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PHOTOGRAPHY

ITS PRINCIPLES AND PRACTICE

By

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SECOND EDITION

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TO MY PARENTS

and

A VERY DEAR FRIEND

PREFACE TO SECOND EDITION

In the three years that have elapsed since the appearance of the first edition, the results of continued investigation of the principles of the photographic process have been such as to render necessary a thorough revision of certain portions of this work. Much of that portion of the chapter on emulsions which deals with the nature of the sensitivity centers has been rewritten to bring this section into line with recent investigations on this subject. Several alterations have been made to the chapter on orthochromatics and the material on the chemical constitution of color sensitizing dyes is new.

The chapter on the latent image has been largely rewritten; the older theories, such as the sub-halide, are discussed frankly from the historical viewpoint and the emphasis has been placed, where it properly belongs, on the modern theories of latent image formation. In view of the current discussion regarding the usefulness of H. and D. speeds, it has been thought advisable to add to the chapter on sensitometry a section on H. and D. speeds and effective speeds. A new section has been added on the reciprocity function and the more generally used polarization photometers have taken the place of the now obsolete H. and D. instrument, a description of which was included in the first edition because its principle is more easily understood by the student than the more complex polarization instruments.

Other additions include a table of the properties of the more common developing agents, sections on the exhaustion of developing solutions through continuous use, development at high temperatures, the newer theories of the fixing process, and a revision of the material on the characteristics of printing papers.

It is a pleasure to acknowledge the suggestions and criticisms of my good friend Dr. S. E. Sheppard and the helpful advice of many others, especially Dr. C. W. Burchard, Professor of Organic Chemistry at this institution.

C. B. Neblette, F.R.P.S.

College Station, Texas
January 4, 1930

PREFACE TO FIRST EDITION

Manifold as are the applications of photography in all branches of science and industry and great as has been the increase in our knowledge of its basic principles in recent years, comprehensive and adequate instruction in the subject has been largely neglected by our universities and technical institutions. Despite its daily application to the practice of almost every branch of science and industry, and indeed in every walk of life, as well as its importance from the standpoint of pure science, there is not, within the knowledge of the writer, a single university or technical institution in this country which offers a thorough and complete course in the science and practice of photography.

The literature of photography is widely scattered among a large number of journals, some of which have long since disappeared, while until comparatively recently no worthy attempt had been made towards the abstracting and indexing of photographic information. Excluding papers in the periodical press, photographic literature can for the most part be divided into two classes: (1) works of an elementary nature designed for the beginner and paying but scant attention to the fundamental scientific basis of the subject and (2) works of an encyclopedic nature designed principally for reference purposes, such as Dr. J. M. Eder's monumental work in German, the *Ausführliches Handbuch der Photographie* and Fabre's *Traite Encyclopedique de Photographie* in French. Valuable as these works may be, they are not textbooks in the true sense of the word and there is in fact no work dealing both with the science as well as the practice of photography which is especially adapted for use as a text.

The present work is an attempt to meet that need. It embraces the features which several years' experience in the teaching of the subject has shown the writer to be desirable in a work designed for college instruction. No attempt has been made to compile a complete treatise on the subject, while at the same time the fact has been kept in mind that a superficial treatment of the subject, one which is concerned with *effects* rather than causes and with *operations* rather than *scientific principles,* is undesirable in a work of collegiate grade. Accordingly it has been the aim of the writer throughout to present as clearly and as concisely as possible the fundamental principles of the science of photography, omitting nothing of primary importance necessary to an understanding of the subject and paying particular attention to the proper coördination of the facts to one another.

The practical side has not been lost sight of, however, and several of the chapters deal with their subject more from the standpoint of technique rather than science. These, it is hoped, will render the work useful not only to the student but to the practical worker as well.

An apology, perhaps, is due for the omission of certain subjects and for the brief treatment accorded to others. This was, however, to a certain extent, demanded by the scope of the work which is that of a text rather than a treatise. Accordingly a large number of the unsettled controversies have either been omitted, or but briefly treated, as it was felt inadvisable to consider in a work of this nature subjects which still await satisfactory solution.

Footnotes throughout the text will show the extent to which I am indebted to others, while to the following authorities I desire to place on record my appreciation of their invaluable services: Dr. C. E. K. Mees, Dr. S. E. Sheppard, Dr. A. P. H. Trivelli, all of the Eastman Research Laboratory; Mr. F. F. Renwick; Dr. Walter Clark of the British Photographic Research Association; Dr. Hermann Kellner of the Scientific Department, Bausch and Lomb Optical Company; Carl J. Reich of the Gundlach-Manhattan Optical Company; Mr. George E. Brown, Editor of the *British Journal of Photography;* Mr. Frank Roy Fraprie and Mr. E. J. Wall of *American Photography;* Drs. Walters and Davis of the Bureau of Standards; and Miss Bess Spence of this institution who has assisted me in seeing the work through the press. To all others who have assisted in the preparation of this work in any way, a cordial acknowledgment of appreciation is also due.

C. B. NEBLETTE

COLLEGE STATION, TEXAS, 1926

CONTENTS

CHAPTER I. The Development of Photography.............. 1

Introduction. The Development of the Camera. Jean Baptiste Porta. The Camera Obscura with Lens. Early Records of the Photochemical Action of Light. The Forerunners—Davy and Wedgwood. Life and Work of Joseph Nicephore Niepce. Life and Work of Jacques Mande Daguerre. The Daguerreotype Process. Later History of the Daguerreotype. The Positive Process of Bayard. Life and Work of Henry Fox-Talbot. The Calotype Process. Miscellaneous Paper Processes. Introduction of Glass. Scott-Archer and the Introduction of Collodion. The Collodion Process. Inconveniences of the Collodion Process. Modifications of the Collodion Process. Introduction of Collodion Emulsion. Introduction of Gelatino-Bromide Emulsion. Improvements in the Gelatino-Bromide Process. Development of Printing Processes with Silver Salts. Platinum Printing Processes. Printing Processes with Bichromated Colloids.

CHAPTER II. The Camera and Darkroom.................. 38

The Box Camera. The Miniature Camera. Folding Hand Cameras. The Professional Camera. The Reflex Camera. The Principal Adjustments of Cameras. The Swing Back. The Reversible Back. Other Movements. Shutters. Tripods. The Darkroom. Ventilation. Size. Arrangement. Water Supply. The Illumination of the Darkroom. The Safelight. The Efficiency of Darkroom Safelights Trays, Tanks, Commercial Tanks and Graduates. Miscellaneous Features.

CHAPTER III. Photographic Optics........................ 65

Introduction. Refraction of Light. Dispersion. Lenses and Image Formation. Image Formation according to the Gauss Theory. The Position of the Nodes. The Principal Focus of a Lens—Focal Length. Focal Length and Size of Image. Angle of View. Conjugate Focal Distances. Extra Focal Distances. Theory of Depth of Focus. Factors Controlling Depth of Focus. The Intensity of the Image. Speed of Lenses—Systems of Diaphragm Notation. Effective Aperture. Loss of Light in Lenses Due to Absorption and Reflection. Variation in Relative Aperture with Distance of Subject.

CHAPTER IV. The Aberrations of the Photographic Objective.. 89

Introduction. Chromatic Aberration. Spherical Aberration. Coma. Curvative of Field. Distortion. Astigmatism. Flare and Flare Flare Spot. Unequal Illumination.

CHAPTER V. The Photographic Objective.................. 105

PART I. THE ASTIGMATS: The Single Collecting Lens. The Single Achromat. Semi-Achromatic or Soft-Focus Lenses. The Aplanat or Rapid Rectilinear. The Petzval Portrait Lens.

PART II. THE ANASTIGMATS: Introduction. Cemented Symmetrical Anastigmats. Alternate Form of the Double Anastigmat. The Four Glass Element—the Protars. The Five Glass Element. Symmetrical Lenses with Air-Spaces. The Gauss Construction. Steinheil's Unofocal. Graf Variable and Anastigmat. Beck's Neostigmat and Isostigmat. The Plasmat. Dallmeyer's Stigmatic. Rudolph's Early Protars. The Unar. The Tessar. Combination of Air Space and Cemented Surface—Later Developments. Serrac. X-Press. Radiar. The Cooke Triplet. Development of the Cooke Triplet after H. D. Taylor. The Aviar. Aldis. Heliar, Dynar. Pentac. Ernostar.

PART III. THE TELEOBJECTIVE: Principle. The Compound Teleobjective. Early Fixed-Magnification Teleobjectives. Anastigmatic Fixed-Magnification Teleobjectives. Dallmeyer's Adon.

CHAPTER VI. The Photographic Emulsion.................. 149

Introduction. The Two Classes of Emulsions. General Outline of Operations in Emulsion Preparation. Gelatine. Light Sensitiveness of Silver Salts. The Preparation of Emulsions. Emulsification. Gelatino-Bromo-Iodide Emulsions. Digestion of the Emulsion. Fog. Theory of Digestion. Eliminating the Soluble Salts. The Silver Bromide Grain of Photographic Emulsions. The Sensitivity of the Silver Halide Grain. Grain Size and Distribution and Its Relation to the Photographic Properties of Emulsions.

CHAPTER VII. Orthochromatics........................... 168

Light and Color—the Spectrum. Visual and Photo-Chemical Luminosity. History of Dye Sensitizing. Known Facts Regarding Color Sensitizing. Constitution of Color Sensitizers. Color Sensitizing Dyes. Color Sensitizing by Bathing. Hypersensitizing. The Theory of Light Filters. Orthochromatic Filters. Contrast Filters. Orthochromatic Methods in Landscape Photography. Orthochromatic Methods in Portrait Work. Photographing Color Contrasts.

CHAPTER VIII. The Latent Photographic Image............. 194

Photo-Physical and Photo-Chemical Change. The Latent Image. Hydrogen Peroxide. Intensification with Hydrogen Peroxide. Sodium Arsenite. Reversal by Chemical Reagents vs. Reversal by Light. Photo-Regression. Physical Development of the Latent Image after Fixation. The Photosalts. Action of Oxidizing and Halogenizing Agents on the Latent Image. Visible Darkening of the Ag Halides. The Latent Image. Modern Conceptions of the Mechanism of Exposure.

CHAPTER IX. Sensitometry.............................. 209

What is Sensitometry? Resumé of Sensitometric Investigation. Standard Light Sources. Sensitometers. Relation of Time and Intensity. Densitometers. Opacity—Transparency—Density. Exposure and Development of Sensitive Materials for Speed Determination. Relation of Exposure and Growth of Density. The Characteristic Curve. The Significance of the Characteristic Curve. Inertia as an Inverse Measure of Speed. Variation of the Inertia. Effective and H. and D. Speeds. Wedge Methods of Sensitometry. The Perfect Negative. Density-Exposure Relation and Correct Reproduction. Latitude of Sensitive Materials. Development and the Reproduction of Contrasts. Constant Density Ratios. An Important Difference. Development and Contrast. Gamma as a Measure of Contrast. Gamma and the Characteristic Curve. Calculation of Gamma. Gamma Infinity.

CHAPTER X. The Exposure of the Sensitive Material......... 240

The Problem. Light Intensity and Exposure. The Subject. Speed of Plate. Speed of Lens. Determination of the Time of Exposure. Exposure Meters. Corrections for Special Subjects. Visual Meters, Types, Principles and Use.

CHAPTER XI. The Theory of Development................. 253

Introduction. The Invasion Phase. The Chemical Reaction within the Cell—The Reduction Phase. The Precipitation Phase. Development as a Reversible Reaction. The Action of Sulphites, Soluble Bromides and Alkali in Organic Developing Solutions. The Physical Chemistry of the Developing Process. The Induction Period. The Velocity of Development. The Velocity Constant. Calculation of the Time of Development for a Given Gamma. Effect of Temperature on Development. Calculating the Temperature Coefficient. Time of Development at Various Temperatures. The Action of Soluble Bromides in Development. The Relative Reducing Energy of Developing Agents.

CHAPTER XII. Organic Developing Agents................. 276

Developing Power. Classification of Developing Agents. Organic Developing Agents. The Significance of Group Relations. Developing Characteristics of Organic Developers. Formulae for Principal Developing Agents. Formula for Combined Developers.

CHAPTER XIII. The Technique of Development............. 293

Introduction. The Sulphites in Development. The Alkalis in Development. The Value of Desensitizers. The Development of Desensitizing Agents. Desensitizing in Practice. Development by Inspection. The Watkins System of Factorial Development. What

Determines the Factor. Accuracy of the Factorial System. Thermo Development. The Watkins System of Thermo Development. Developing Speeds of Commercial Plates. Developers. Instructions. Thermo-Development with Glycin. The Efficiency of Time Development. Development at High Temperatures.

Chapter XIV. The Laws of Fixation and Washing.......... 314

Action of Sodium Thiosulphate on the Silver Halides. The Mechanism of Fixing. Influence of the Concentration of Thiosulphate and Temperature on Time of Fixation. Influence of Ammonium Chloride on the Rapidity of Fixation. When are Plates Fixed? Exhaustion of the Fixing Bath. The Fixation of Prints. Plain Fixing Baths. Acid Fixing Baths. Acid Fixing and Hardening Baths. Troubles with the Acid Fixing and Hardening Bath. Extra Hardening Baths. The Mechanism of Washing. The Efficiency of Washing Devices. The Washing of Prints. Methods of Determining the Presence of Thiosulphate. Hypo Eliminators.

Chapter XV. Defects in Negatives...................... 333

The Why of Defects. Thin Negatives. Dense Negatives. Fog on Negatives. Local Fog. General Fog due to Light. Chemical Fog. Dichloric Fog. Developer Stains. Silver Stains. Miscellaneous Stains. Transparent Spots. Opaque or Semi-Opaque Spots. Miscellaneous Troubles.

Chapter XVI. Intensification and Reduction............... 345

Part I. Reduction. The Three Classes of Reducers. Farmer's Reducer. Mercury and Cyanide. Iodine Cyanide. Belitiski's. Permanganate. Bichromate. Proportional Reducers. Super-proportional Reducers. Theories of Super-proportional Action. Practice of Persulphate Reduction. Intensification, Definition, Methods and Characteristics. Mercury Intensifiers. Monkhoven's. Mercuric Iodide. Silver Intensifiers. Chromium Intensifiers. Uranium. Sulphide. Lead. Copper. Sensitometry of Intensification. Local Reduction and Intensification.

Chapter XVII. Printing Processes with Silver Salts......... 364

Part I. Developing Papers: Characteristics of Printing Papers. Adapting the Paper to the Negative. Developing Papers. Exposure. Developers. The Safelight. Development. Factorial Development. The Proper Factor. The Short Stop. Fixing. Washing. Drying. Alteration of Contrast Reduction and Intensification of Prints. The Glazing of Prints.

Part II. Gelatine P-O-P: Toning. Instantaneous Toning. Black Tones with P-O-P. Fixing.

Chapter XVIII. Projection Printing........................ 390

Introduction. Fixed Focus Enlarging Cameras. Apparatus for Projection Printing with Daylight. Apparatus for Projection Printing with Artificial Light. Self-focusing Apparatus for Projection Printing. Illuminants for Projection Printing. The Mercury-Vapor Lamp. The Electric Arc. Incandescent Lamps. Securing Even Illumination without Condensers. The Condenser in Projection. Condensing Lenses with Diffusing Media. The Projection Lens. The Projection Easel. The Negative for Projection Printing. The Technique of Projection Printing. Focusing. Determining Exposures in Projection Printing. Relative Exposure, Scale and Aperture in Enlarging or Reduction. Enlarging from Small Negatives. Introducing Clouds in Enlargements. Enlarged Negatives.—Sensitive Materials.—Exposure. Development.

Chapter XIX. Lantern Slides and Transparencies........... 419

The Negative. Lantern Plates. Printing Frame for Contact Printing Exposing. Printing by Projection. Developers. Development. Fixing, Washing and Drying. Masking. Spotting. Binding. Advertising Slides. Toning of Lantern Slides by Restrained Development. Physical Development. Colors on Development with Thiocarbamide. Toning of Lantern Slides. Reduction and Intensification of Slides.

Chapter XX. The Toning of Developed Silver Images....... 431

Introduction. The Sulphur Toning Processes—the Print. The Hypo-alum Process. Zanoff's Controlled Hypo-alum Method. Sulphur Toning with Acid Hypo. Toning with the Polysulphides. Single Solution Sulphur Toning Processes (Shaw's Process). The Indirect Process of Sulphide Toning. Rebleaching of Sulphide Toned Prints. Indirect Sulphide Toning with Intermediate Development. Mercury Sulphide Toning (Bennett's Process). Toning with Copper. Toning with Uranium. Iron Toning Processes. Toning with Vanadium. Minor Toning Processes.

Chapter XXI. Platinotype and Iron Printing Processes...... 452

Introduction. Theory of the Process. Commercial Papers and their Treatment. Exposure. Development. Variations in Contrast. Variations in Color. Silver Platinum Papers. The Kallitype Process. Blue Printing.

Chapter XXII. Printing Processes Employing Bichromated Colloids. I. (Carbon and Carbro).... 462

The Chemistry of Pigment Printing with Bichromated Colloids. The Carbon Process. Carbon Tissues. Double and Single Transfer. Sensitizing the Tissue. Exposure. Development. Double Transfer. Transferring to Rough Papers. The Carbro Process. The Bromide Print. Sensitizing the Tissue. Transfer. Redevelopment of the Bromide Print. Development of the Carbro. Carbon on Bromide. Multiple Printing.

CHAPTER XXIII. Printing Processes Employing Bichromated Colloids. II. (Gum-Bichromate and Allied Processes) 481

Introduction. Materials. The Negative. Formulas. Effect of Varying Proportions of the Coating Mixture. Coating. Drying. Exposure. Development. Registration. Gum-Bromide and Gum-Platinum. The Powder Processes. Formula of E. J. Wall. Resinopigmentype.

CHAPTER XXIV. Printing Processes Employing Bichromated Colloids. III. (Oil, Bromoil and Transfer 494

Introduction. Materials for the Oil Process. Papers for the Oil Process. Brushes. Pigments. Sensitizing. Exposing. Pigmenting. Incorrect Exposure. Drying and Mounting. Duvivier's Process. The Bromoil Process. The Choice of the Paper for the Bromide Print. The Production of the Bromide Print. Bleaching of the Bromide Print. Chemical Theory of the Bleaching Operation. Fixing. Producing the Relief. Pigmenting. Namias Method of Pigmenting. Defatting the Finished Bromoil. Bromoil Transfer. The Bromide Print. Preparation of the Bromoil. The Transfer Paper. The Transfer Press. Transferring the Pigment. Zaepernick's Chemical Transfer Method. Multiple Transfer.

CHAPTER XXV. Copying 520

Introduction. Apparatus for Copying. Methods of Illuminating the Print. Copying Cameras. The Objective for Copying. Focusing. Copying to Scale. Exposures in Copying. The Copying of Subjects in Pure Black and White. Development of Process Plates. Copying Photographs or Like Subjects in Monochrome. The Photography of Colored Objects. Photography of Small Objects in the Studio.

CHAPTER XXVI. Natural Color Photography 537

Introduction. Processes of Direct Color Photography—The Bleach Out Process. Processes of Direct Color Photography—Processes of Light Interference. Natural Color Photography by Trichromatic Methods. Making the Three Color-Sensation Negatives. Additive and Subtractive Three-Color Photography. Subtractive Printing Processes. Multi-Color Screen Plates. The Autochrome Plate.

The Compensating Filter. Handling of the Autochrome Plate. Exposure. Development. Reversal of the Image. Varnishing. After-Treatment of Autochromes. The Agfa Color Plate. Duplicating Processes of Screen-Plate Color Photography. The Duplex Method.

APPENDIX. A List of the More Important Reference Works on Photography 559

REFERENCES TO TECHNICAL JOURNALS 561

INDEX 603

ILLUSTRATIONS

FIG.
1. The camera obscura from an old print. (Courtesy of the Smithsonian Institution) 2
2. Johann Heinrich Schulze. (From Eder's biography) 6
3. Thomas Wedgwood. (Chalk drawing, author unknown) 7
4. Joseph Nicephore Niepce (Courtesy of the Société Française de Photographie) 9
4*a*. Birthplace of Niepce 10
4*b*. Statue to Niepce 10
5. A heliographic print by Niepce, 1824 11
6. Louis Jacques Mande Daguerre 12
7. Tomb of Daguerre. (Courtesy of the Société Française de Photographie) 14
8. Fuming cabinet for the Daguerreotype process 15
9. Developing box for the Daguerreotype process 16
10. An early Daguerreotype portrait. Often stated to be the first portrait by photography 17
11. William Henry Fox-Talbot 19
12. Frederick Scott Archer. Drawing from an old print reproduced in J. Werge—*The Evolution of Photography* 22
13. The wet collodion process in the field. (From an old manual) 24
14. Portable laboratory for field use with wet collodion 25
15. Dr. Richard Leach Maddox 27
16. Typical miniature camera for plates and for roll film 39
17. Hand cameras for plates and for roll film 41
18. Professional view camera 43
19. Principle of the reflex camera 44
20. Principle of the swing back. Use of the swing back for securing greater depth of focus 46
21. Ventilation of the darkroom. (Courtesy of Eastman Kodak Company) 53
22. Floor plan of darkroom for amateur use 54
23. Eastman indirect darkroom lamp 57
24. Design for indirect darkroom lamp. (Krug, *American Annual of Photography*, 1922) 57
25. Eastman developing lamp 58
26. Wratten darkroom safelight lamp 58
27. Drying cabinet for plates and films 64
28. The principles of refraction 66
29. Refraction in a medium with parallel sides 67
30. Refraction in a prism 67
31. Dispersion in a prism 68
32. Principal forms of simple lenses 68
33. Image formation with positive or converging lenses 69

34. Course of light pencils through a negative lens 69
35. Image formation according to the Gauss theory 70
36. Image formation according to the Gauss theory 70
37. Position of the nodes in common forms of simple lenses 71
38. Table for the calculation of angle of view 73
39. Graphic illustration of the principle of depth of focus. (Von Rohr) 79
40. Intensity of the optical image. (Brown) 81
41. Chromatic under correction 90
42. Chromatic over correction 90
43. Irrationality of dispersion 91
44. Spherical aberration 93
45. Coma. (Kellner) 94
46. Two forms of coma. (Piper) 95
47. Curvature of field. (Under-correction) 96
48. Curvature of field. (Over-correction) 96
49. Distortion 97
50. Under and over correction for distortion 98
51. Astigmatic deformation. (Kellner) 100
52. Optical flare 101
53. Constriction of aperture for the marginal pencils. (Brown) 102
54. Greater focal length of marginal pencils resulting in lower intensity. (Brown) 103
55. The angling of the oblique ray. (Brown) 103
56. Relation between the angle of view and the diminution of the optical intensity of the image. (Zschokke) 104
57. Wollaston's meniscus 105
58. The Chevalier or French landscape lens 106
59. Grubb's landscape lens 106
60. Dallmeyer's rapid landscape lens 106
61. Goddard's landscape lens—Dallmeyer's rectilinear landscape lens 107
62. Sutton's triplet 109
63. Dallmeyer's triple achromatic 109
64. Harrison and Schnitzer's Globe lens 109
65. The Aplanat or R. R. 110
66. Portrait of Petzval 111
67. Petzval's portrait objective 112
68. Modifications of the Petzval portrait objective. ((*a*) Dallmeyer, (*b*) Voigtlander, (*c*) Zinc-Sommer) 112
69. Cooke F/1.5 modification of the Petzval construction 113
70. The Goerz Dagor 115
71. Watson's Holostigmat 116
72. The Collinear and Orthostigmat of Voigtlander and Steinheil 116
73. Rudolph's Protar Series VII*a* 117
74. The T-R anastigmat 118
75. The Celor and Syntor of Goerz 119
76. The Dogmar of Goerz 120
77. The Gaussian objective 120

78. Rudolph's Planar.......... 121
79. Kollmorgen's Aristostigmat.......... 122
80. Lee's T. T. H. Opic.......... 122
81. The Leiss Biotar F/1.4.......... 123
82. Rudolph's Plasmat.......... 123
83. Steinheil Unofocal.......... 125
84. Graf Anastigmat.......... 126
85. Beck's Isostigmar.......... 127
86. Beck's Neostigmar.......... 128
87. Dallmeyer Stigmatic.......... 128
88. Rudolph's unsymmetrical Protar.......... 129
89. Rudolph's Unar.......... 130
90. Rudolph's Tessar.......... 131
91. Dallmeyer Serrac.......... 132
92. Ross X-press.......... 133
93. Gundlach Radiar.......... 133
94. Cooke triplet.......... 134
95. Action of the central diverging lens.......... 135
96. Cooke Aviar.......... 136
97. Aldis Series II*a*.......... 137
98. Aldis Series II and III.......... 137
99. Harting's Heliar.......... 137
100. Harting's Dynar.......... 138
101. Dallmeyer's Pentac.......... 138
102. The Ernostar.......... 139
103. Dallmeyer's compound teleobjective.......... 141
104. Petzval's orthoskop.......... 142
105. Martin's Bis-Telar.......... 143
106. Zeiss Magnar.......... 143
107. Ross Telecentric.......... 143
108. Dallmeyer large Adon.......... 143
109. Booth teleobjective.......... 144
110. Radiar teleobjective.......... 145
111. Cooke Telekinic F/3.5.......... 145
112. Zeiss Teletessar.......... 146
113. Ross Teleros.......... 146
114. Lee's T. T. H. Telephoto.......... 146
115. Voigtlander's Tele-Dynar.......... 146
116. Dallmeyer's Adon.......... 147
117. Emulsion press.......... 161
118. Photographic emulsion under microscope.......... 162
119. Size frequency distribution of silver halide grains in a portrait film and lantern slide emulsion.......... 166
120. Three-color print of the spectrum
121. Visual luminosity of the spectrum after Abney.......... 169
122. Spectral sensitiveness of the silver halides.......... 170

123. Spectral Sensitiveness of a Gelatino-bromo-iodide Emulsion Color-Sensitized with Various Dyes.................................. 178
124. Portrait on ordinary and panchromatic emulsions.................... 188
125*a*. Photograph of manuscript in blue with red corrections using a green filter 190
125*b*. Photograph of manuscript in blue with red corrections showing use of red filter.. 190
126. Wood sections on ordinary and panchromatic plates. (Courtesy of Ilford Ltd.).. 192
127. Chapman Jones plate speed tester.................................... 212
128. H. and D. sector wheel and exposing apparatus...................... 212
129. Densitometers. (1) Martens; (2) Filmograph; (3) Sanger-Shepherd Density Meter.. 215
130. Illustrating the relation of opacity, transparency and density.......... 218
131. The characteristic curve.. 222
132. Step chart illustrating the theory of the characteristic curve........... 223
133. Characteristic curve secured by crossed wedges...................... 227
134. Latitude and the characteristic curve................................ 231
135. Development and constant density ratios............................ 231
136. The geometry of gamma. (Brown)................................... 236
137. Sea and sky... 242
138. Sea view and shipping... 243
139. Open landscape.. 243
140. Average landscape... 244
141. Outdoor portrait.. 245
142. The Invasion phase of development. (Mees)........................ 254
143. Growth of density with time of development. (Neitz)............... 260
144. Curve showing growth of density with time of development. (Neitz).. 260
145. H. and D. method for calculating the time of development for given gamma 264
146. Watkins method of calculating the T. C.............................. 270
147. Stokes time development chart....................................... 271
148. Effect of a soluble bromide in the developing solution on the plate curve, 272
149. Density depression with a soluble bromide. (Neitz).................. 273
150. Effect of soluble bromide on the densities. (Watkins)............... 273
151. Influence of temperature on time of fixation......................... 316
152. Influence of concentration of hypo on time of fixation................ 317
153. Influence of ammonium chloride on the time of fixation............... 319
154. Windoe's washing apparatus.. 328
155. Trox washer for roll film.. 329
156. Sensitometric action of different reducers. (Neitz and Huse)........ 346
157. Action of a proportional reducer on the plate curve. (Neitz and Huse), 350
158. Sensitometry of photographic intensification. (Neitz and Huse)...... 361
159. Bench for local reduction. (*British Journal of Photography*)........ 363
160*a*. 160*b*, 160*c*. Adapting the scale of the printing paper to the negative..
161. Printing machines for amateur and for professional use.............. 373
162. Effect of time of development upon the characteristic curve of paper emulsions 376

163. Electrically operated print washer. (Pako) 379
164. Centrifugal water pressure type of print washer. (Halldorsen) 380
165. Rotary belt dryer. (Sickle) 381
166. Principle of projection printing 390
167. Box enlarging camera 391
168. Daylight enlarging camera 392
169. Projection printing apparatus for use with daylight 393
170. Enlarging lantern for artificial light 394
171. Proper position of the carbons of an arc light for use with alternating current 396
172. Parallax reflector for use with incandescent electric sources 398
173. Securing even illumination with five incandescent electric sources 398
174. Forms for the lighthouse using reflected light. (Wall) 399
175. The function of the condenser 400
176. Conjugate foci in enlarging 401
177. Adjustment of the light source with condensers 402
178. Loss of light between condensers due to the use of a long focus lens for projection. (Candy) 404
179. Loss of covering power owing to the use of short focus projecting lens with condensers. (Candy) 404
180. Ingento enlarging easel for use with printing frame 406
181. Westminister enlarging easel 406
182. Scatter of light by negatives. (Callier) 408
183. Graduating focusing scale for enlarging. (Lockett) 412
184. F and S Lantern slide printing frame 420
185. Century lantern slide camera for reduction 421
186. Slide making by reduction using daylight 422
187. Device for holding lantern plate in position when using enlarger for lantern slide making by reduction. (Charles) 423
188. Actinometers for carbon printing 468
189. Squeegee board for carbro. (Farmer) 476
190. Curves showing the influence on contrast of variations in proportions of gum, pigment and sensitizer in the gum-bichromate process. (Anderson) 484
191. Owens' frame for multiple printing 487
192. Zerbe's method of registration 489
193. Proper position of the brush in pigmenting. (Mortimer and Coulthurst, *The Oil and Bromoil Processes*) 500
194. Results in pigmenting. (Partington) 510
195. Transfer presses 515
196. Prett's transfer press 516
197. Copying stand 520
198. Book holder for copying 520
199. Illumination of the copy using daylight 522
200. Copying apparatus for artificial light. (Rose, *The Commercial Photographer*) 522

201. Method of securing white or black backgrounds. (Photo. courtesy of D. J. Pratt) 536
202. Sanger Shepherd three-color camera 541
203. Butler's one-exposure, three-color camera 541
204. Autochrome screen. × 125 547
205. Duplex screen 554

CHAPTER I

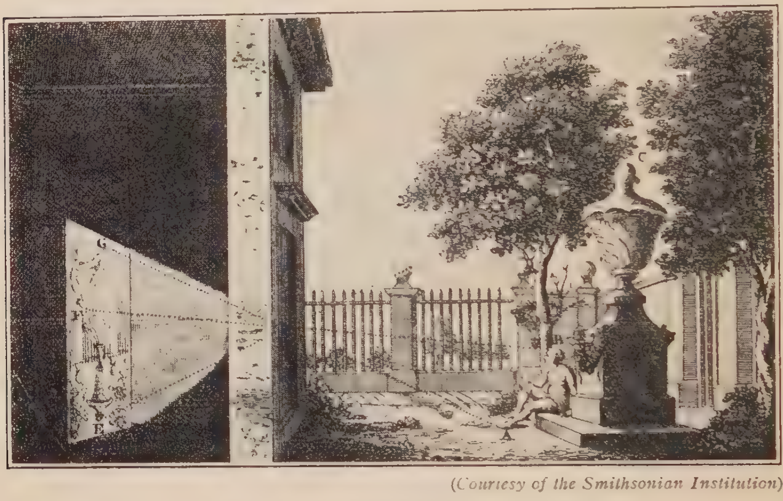
THE DEVELOPMENT OF PHOTOGRAPHY

Introduction.—Photography is the science of obtaining images of objects by the action of light on sensitive substances. The word *photography* is due probably to Sir John Herschel and is derived from two Greek words (φῶς = light, γραφια = write) meaning to draw by light.

The two sciences of optics and chemistry form the basis of photography, the former being concerned with the production of the image in the camera, the latter with the composition and treatment of the sensitive surface which reproduces the image cast upon it by the lens.

The Development of the Camera.—The invention and development of the camera forms a most important phase in the history of photography. *Camera* is a Latin word originally meaning an enclosure with a vaulted, or arched, cover, but in course of time came to mean a room. Thus the *camera obscura* means a dark room, except for the illumination which comes through the small opening which serves as the lens. (Fig. 1.) We do not know by whom, or at what date, the principle of the camera obscura was first discovered. There was, properly speaking, no invention of the camera obscura, for the principle is a natural phenomenon which must certainly have been observed many times by man without having excited any particular interest until someone more enterprising than the rest set about to find the cause of the phenomenon and its possible applications. At whatever date this may have taken place, we have at least a reference to the principle of the camera obscura as early as the time of Aristotle. This learned Greek in his *Problemata* published about 350 B.C. refers to the fact that the image of the sun formed by the rays of light passing through a square aperture appears circular. He also noted the amplification of the image as the distance from the aperture is increased. Even a man with his intellect, however, appears to have been unimpressed, so that the camera obscura, properly speaking, escaped him and he has really no place in its history.

From the time of Aristotle there is no mention of the camera obscura for many hundred years. Alhazen in his *Thesaurus Opticæ* written in the eleventh century, although not published until 1572, seems to have been more or less familiar with its principle although he does not mention it specifically. Roger Bacon in his *Perspectiva,* published in 1267, has a passage which many have taken as the first description of the camera obscura, but it is so indefinite that it may be equally as well regarded as applying to the projection of images. There are other passages in his *Opus Majus* which seem to indicate a knowledge of the principles of the camera obscura but these likewise are couched in such vague terms that we are hardly justified in crediting him with the discovery of the camera obscura.



(*Courtesy of the Smithsonian Institution*)

Fig. 1. The Camera Obscura from an Old Print

The first precise and complete account of the camera obscura is to be found in one of the unpublished manuscripts of Leonardo da Vinci quoted by Venturi in his *Essai sur les Ouvrages physico-mathematiques de Leonardo da Vinci* which was published at Paris in 1797. The following is Venturi's translation of the passage in the works of Leonardo:

> The following experiment shows how objects send their images to intersect on the albiginous humor inside the eye. When the images of illuminated objects enter into a very dark chamber by a small round aperture, if you receive these images in the interior of the room on a piece of white paper placed at some dis-

> tance from the aperture, you will notice on the paper all the objects in their proper forms and colors: they will be lessened in size and will be reversed, and that in virtue of the intersection already noticed. If the images come from a place lit by the sun, they will appear as if painted on the paper, which should be very thin and looked at from behind. The aperture should be made in a very thin piece of sheet iron.

Leonardo then goes on to give a diagram showing the arrangement of the aperture and screen and the course of the light rays. The manuscript is undated, but as Leonardo died in 1519 it probably dates from several years previously. It is noteworthy that he does not refer to it in any way as an invention, which would lead one to believe that he was not sure of having been the first to describe the same.

In Cæsariano's translation of Vitruvius' *Treatise on Architecture,* published at Como in 1521, there is a passage referring to the camera obscura as having been discovered by a Benedictine monk, Don Papnuito. Libri in his *Historie des sciences mathematiques en Italie* (Paris, 1841) says that although this is the first published description of the camera obscura, the observations of Leonardo must certainly have been made at an earlier date.

Maurolycus, an eminent mathematician of Messina, in his *Photismi de Lumine et Umbra ad Perspectivam et radiorum incedentiam facientia,* published in 1611, but finished in 1521, treats the subject mathematically and gives several theorems relating to the passage of light through small apertures and was apparently well acquainted with the formation of images in this way.

The next references to the camera obscura are found in Germany, where we find Erasmus Reinhold and his pupils Gemma Frisius and others using the same to observe eclipses of the sun without danger to the eyes. Reinhold probably used the camera obscura in this way as early as 1540.

Jean Baptiste Porta.—The connection of Jean Baptiste Porta with the discovery of the camera obscura arises from a passage in his *Magia Naturalis,* a remarkable work published in Naples, 1553, when he was fifteen years of age. Although there are at least five accurate and precise descriptions of the camera obscura prior to the time of Porta, still he is popularly credited with its discovery. It is quite likely that this misconception arose from the fact that Arago, the eminent secretary of the French Academy of Sciences, in his address before that body on the occasion of the presentation of the details of the Daguerreotype process took the opportunity to make a few remarks on the historical phases of the subject in which he referred to the work of Porta with the camera obscura. There is nothing to show that Arago had investigated the subject thoroughly and, although he did not distinctly credit Porta with the discovery of the camera obscura, the prominence given him by one of Arago's eminence established him in the popular mind as the inventor of the camera obscura. As a matter of fact, Libri, a colleague of Arago, in a work on the history of the mathematical sciences in Italy, already referred to, called attention to the work of Leonardo and several others who anticipated Porta in the discovery of the camera obscura. This work, however, apparently never reached the photographic fraternity, with the result that year after year the writers of textbooks in referring to Porta as the inventor of the camera obscura firmly established the myth in the popular mind and it was not until the appearance of Dr. Eder's *Geschichte der Photographie,* and the work of Waterhouse, that the work of Porta's predecessors was properly brought before the photographic world.[1]

The Camera Obscura with Lens.—The first definite description of a camera obscura with a lens is found in a work on perspective, *La Pratica della Prospectiva,* by a Venetian nobleman, Daniello Barbaro, which was published at Naples in 1568. In 1585, seventeen years after the appearance of this work and four years prior to the appearance of the second edition of Porta's *Magia Naturalis,* in which the description of the camera obscura with lens occurs, another Venetian nobleman, Giovanni Battista Benedetti, in a book of mathematical and physical observations published at Turin, again refers to the camera obscura with lens.

The lens used by Barbaro and Benedetti was planoconvex in form. Kepler, who took up the study of the camera about the beginning of the seventeenth century and investigated it thoroughly both theoretically and practically, was the first to perceive the advantage of a compound objective composed of concave and convex lenses. In his *Dioptrice* published in 1611, he deals with the principles of refraction, of image formation, and the properties of various forms of lenses and their combinations. He speaks of the disadvantages of the planoconvex form as regards the small field and the advantages of the use of a concave lens with the convex. Kepler really did a great deal towards placing the optics of the camera on a firm foundation, a branch of his work which has not received the attention which it deserves.

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[1] For a biography of Porta and an account of his predecessors see *Bull. Soc. franc. Phot.,* 1923, **10**, 52.

Early Records of the Photochemical Action of Light.—The tanning of the skin by light is one of the many common evidences of the action of light which could hardly escape the attention of man, even in the savage state, but this action is so slow that it is not sufficiently striking to excite more than casual interest. More than 300 years before Christ, Aristotle observed that the green color of plants was due to light, for plants which had become bleached in the dark turned green again on exposure to light. The first observation on record of the action of the atmosphere on silver is by Pliny about 100 A.D., but his observations are probably only a record of the action of the atmosphere on metallic silver. In the eighth century, however, Jabir Ibn Hayyam, often called Geber, observed the darkening of silver nitrate on exposure to atmospheric action.

In 1556 Georgius Fabricus recorded the fact that crude silver chloride, or horn silver, an ore frequently found in the mines of Frieburg, darkens on exposure, and Boyle, an early English chemist, writing about 1686 speaks of the sensitiveness of gold.

In 1725 a Russian field marshal prepared a remedy in which ferric chloride is used, using the action of light to reduce it to the ferrous state.

That the darkening of the silver salts is due to light and not to the action of various vapors of the atmosphere was first definitely recorded by Johann Henrich Schulze in 1727. (Fig. 2.) While experimenting at an open window with a solution of chalk and aqua regia, which accidentally contained a trace of silver, he was surprised to find that the surface of the solution which was exposed to light had changed to a dark purple color, while the body of the solution removed from the light had not changed. Following up his observations, he made a fresh solution of chalk and aqua regia, which he exposed to light under precisely the same conditions as the first solution. As this mixture was unaffected, he rightly concluded that the sensitiveness of the first solution had been due to the trace of silver. Cutting a stencil in opaque paper he placed the same around a bottle containing some of the mixture and exposed it to light. In this way the words or sentences were accurately and distinctly reproduced on the chalk sediment and the result was looked upon as a marvel by ignorant people.

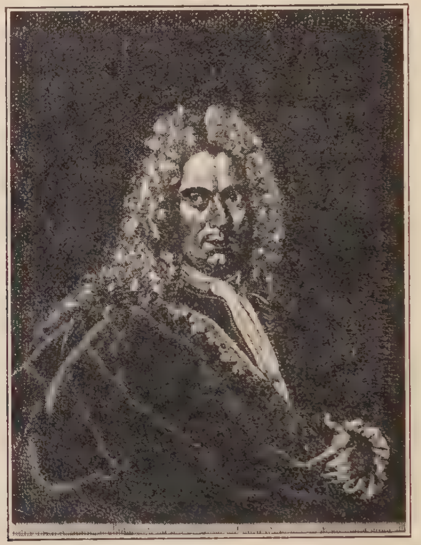

FIG. 2. Johann Heinrich Schulze. (From Eder's biography)

While Schulze was undoubtedly the first to secure an image by the agency of light, his work, although far in advance of his time, is hardly sufficient to earn for him the title "Discoverer of Photography" such as has been given him by Eder and others. The work of Schulze was a great advance, and we are certain a great stimulus to later work along similar lines, but as he made no attempt to use the camera obscura, nor to "fix" the image which he obtained, it seems hardly fair that he should be termed "Discoverer of Photography."[2]

In 1763, Dr. William Lewis published an account of his investigations on the cause of the discoloration of bone, ivory, wood, etc., when treated with silver nitrate and exposed to light, and in his *History of Discoveries Relating to Light, Vision and Color,* Dr. Joseph Priestley refers to the previous work of Schulze and Lewis. The principal interest, however, which we have in this work of Priestley is its connection with a later experimenter, Thomas Wedgwood, who without doubt was led to the subject through its pages.

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[2] For an interesting biography of Schulze see Eder, *Johann Heinrich Schulze—Der Lebenslauf des Erfinders des Ersten Photographischen Verfahrens und des Begrunders der Geschichte der Medizen.* Wien, 1920.

A full translation of Schulze's paper describing his researches with silver salts appeared in the *Photographic Journal* for 1898, **38**, 53.

In 1777, Carl William Scheele noted the influence of various colors on the rate of darkening and found that blue and violet light were much more active in darkening silver nitrate than red or orange. Scheele also investigated the chemical changes involved in the darkening of silver chloride and discovered that the effect of light on this substance is to cause the evolution of chlorine.

Herschel in 1800 discovered the heat rays beyond the visible red, and the following year Ritter discovered, by photographic means, the existence of the very active *ultra-violet* beyond the visible violet.

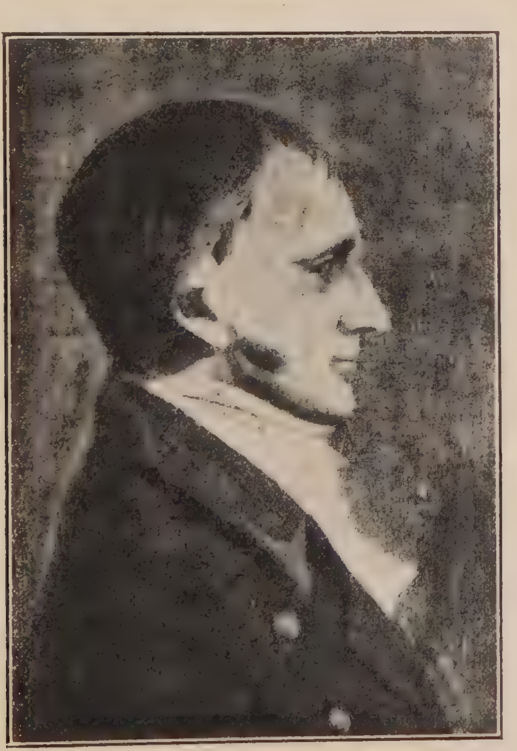

Fig. 3. Thomas Wedgwood. (Chalk drawing, author unknown)

The Forerunners—Wedgwood and Davy.—Neglecting the work of Boulton in 1777, Charles in 1780, and Lord Brougham in 1795, whose claims to the previous discovery of photography are too vague to be seriously considered, we arrive at the important work of Wedgwood, who made the first definite step towards the discovery of photography.

Thomas Wedgwood, fourth son of the great potter Josiah Wedgwood, was born the fourteenth of May 1771. (Fig. 3.) On account of his delicate health, most of his education was conducted at home and he had as tutor a Mr. Alexander Chisolm, who had formerly acted as secretary to Dr. William Lewis and from whom Wedgwood was no doubt able to learn of the work of Schulze and the others who had preceded him.

Wedgwood, together with Humphrey Davy, then a rising young chemist, repeated the work of Schulze with silver nitrate and were able to make prints of leaves, and similar objects, but were unable to prepare a paper sufficiently rapid to permit of its use in the camera obscura. Davy made some important additions to the work of Schulze. He found that silver chloride was more sensitive than the nitrate, and using the concentrated light of a solar microscope, he was able to secure images of small stationary objects on his silver chloride paper. But neither Wedgwood nor Davy were able to find a means of "fixing" the image, or dissolving the unacted-upon silver salt so as to render the image permanent. The poor health of Wedgwood was no doubt partly responsible for this, and the whole subject was abruptly terminated by his death at the early age of thirty-one years. After his death, a joint paper, written probably by Davy, was brought before the Royal Institution and appeared in the *Journal* for 1802 under the following title: *An Account of a Method of Copying Paintings upon Glass, and of Making Profiles by the Agency of Light on Nitrate of Silver,* by T. Wedgwood with observations by H. Davy.

Davy does not appear to have paid any attention to the subject after the death of Wedgwood and no further work on photography was done in England until the researches of Talbot beginning about 1835. While the work of Talbot logically follows that of Wedgwood on account of the close similarity of the methods adopted by the two experimenters, we must first consider the important work of Niepce in France, whose researches began about 1812.

The Life and Work of Joseph Nicephore Niepce.—Joseph Nicephore Niepce (Fig. 4), the first man to obtain a permanent photograph, was born at Chalons-sur-Saone on March 7, 1765. His father was a man of means and Nicephore and his brother, Claude, had a tutor in language and science in which both early showed especial interest. Designed for the Church by his parents, the Revolution upset his plans, and Nicephore joined the army in 1792 and served two years in Italy, when ill health compelled him to resign his commission and return to his country estate, where, having married, he spent the remainder of his long life in scientific pursuits, of which photography was by no means the least. His brother Claude, to whom he was devotedly attached, resided with him until 1811, when, in order to further his scientific work, he left for Paris and finally to Kew in England. Unfortunately Niepce left no written account of his work and our only source of information is from his correspondence to his brother Claude. In 1827 Nicephore visited his brother Claude in England and brought with him some prints and a paper which he hoped to bring before the Royal Society, but having refused to make public the methods employed for making the prints, the rules of the Society compelled them to refuse the communication.

(Courtesy of the Société Française de Photographie)

FIG. 4. Joseph Nicephore Niepce

The same year he met Daguerre in Paris and after overtures lasting

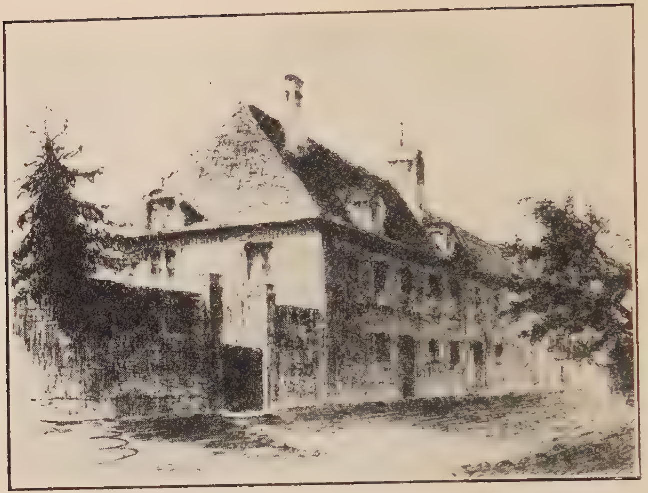

Fig. 4a. Birthplace of Niepce

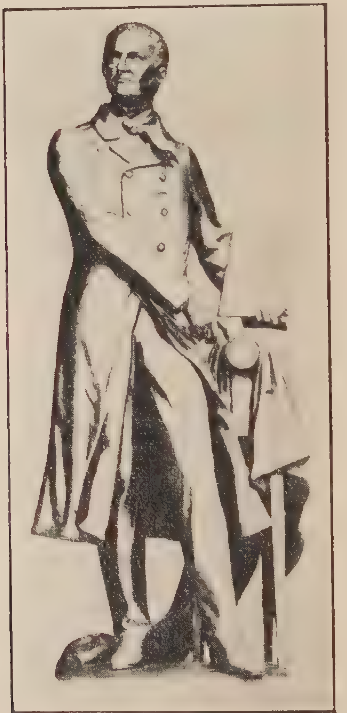

Fig. 4b. Statue to Niepce

two years the two investigators signed articles of partnership to continue for ten years, during which time the two would work to their joint advantage. Niepce made no further advance on his process after this date and on his death in 1833, in his sixty-eighth year, his son Isidore succeeded him in the partnership.

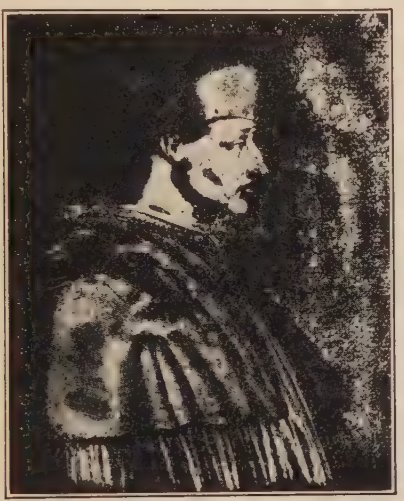

Fig. 5. A Heliographic Print by Niepce, 1824

The basis of the process worked out by Niepce was the discovery that bitumen of Judea or "Jews' pitch" becomes insoluble upon exposure to light. Niepce dissolved bitumen of Judea in oil of lavender and spread a thin layer on stone or metal plates. The sensitized plate was then exposed for several hours under the transparent drawing to be reproduced, after which the plate was immersed in oil of lavender which dissolved the parts unaltered by light, leaving the plate bare in these places and accurately reproducing the outlines of the drawing. By treating the metal plate with acid, an image in relief was produced from which prints could be secured in an ordinary printing press. One of these early prints, dating from 1826, is the Cardinal plate, illustrated in Fig. 5.

A letter of Niepce recently discovered by G. Cromer[3] shows that Niepce was successful in the use of the camera obscura as early as 1826. The letter describes what is perhaps the first permanent reproduction of a natural object by photographic means. The time of exposure required was from six to eight hours, so that, while Niepce may be said to have discovered photography, his process was of little practical value. Nevertheless we must not lose sight of the fact that, although far from perfect, his process was the first by which a permanent reproduction might be secured by photographic means and, furthermore, he was the first to successfully make use of the camera obscura, so that to Niepce belongs a large share in the discovery of photography.

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[3] *Bull. Soc. franc. Phot.*, 1922, **9**, 69.

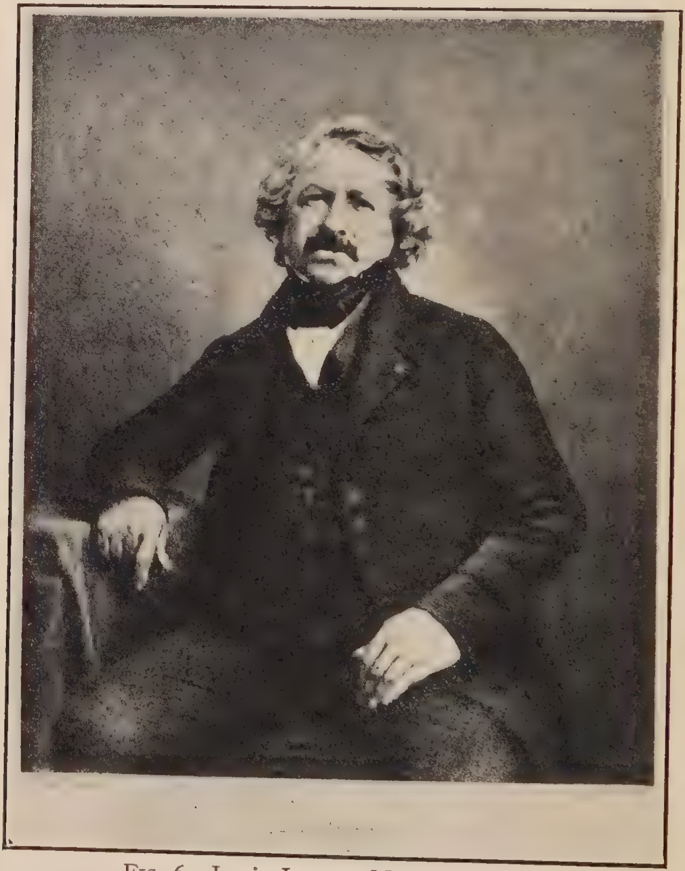
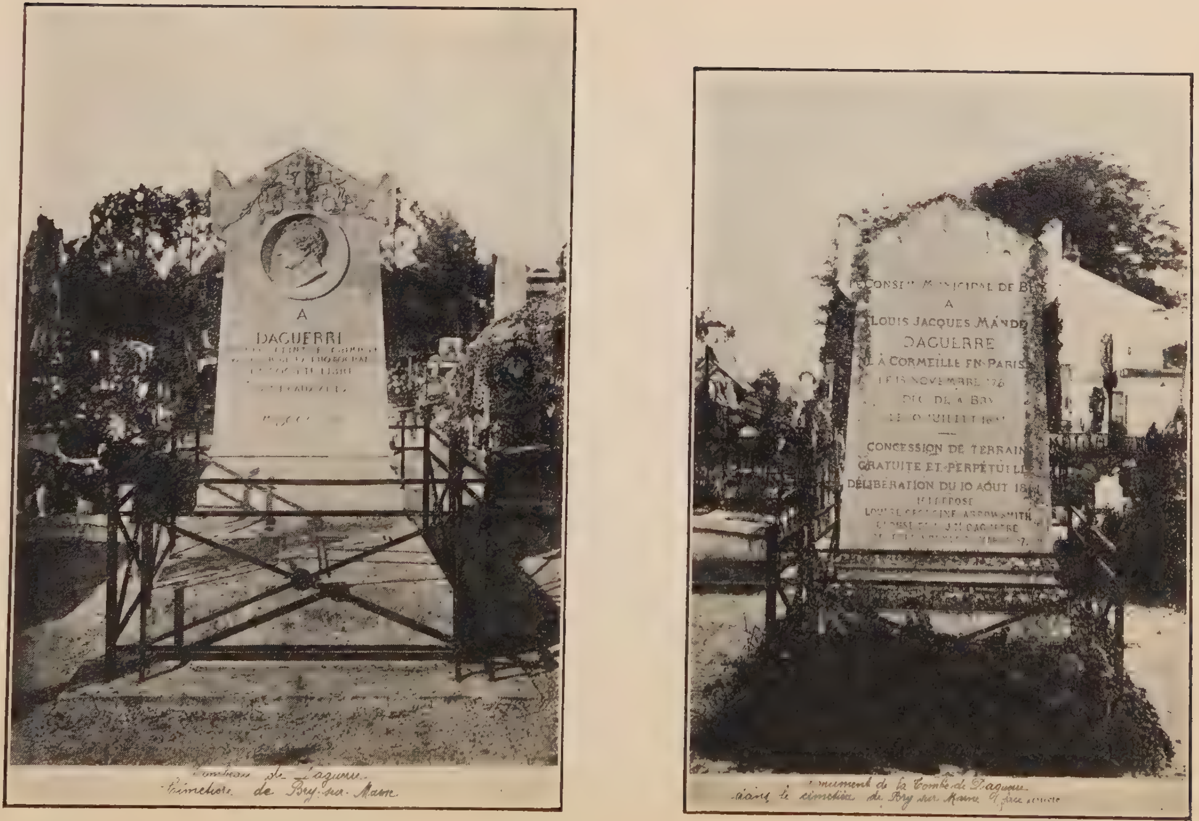


Fig. 6. Louis Jacques Mande Daguerre

The Life and Work of Jacques Mande Daguerre.—Jacques Mande Daguerre (Fig. 6), who invented the Daguerreotype, the first practical process of photography, was born at Cormeilles, a small village about ten miles from Paris, on November 18, 1787. His father was court crier of the village and his mother from one of the village families. During the Revolution his father lost his position and moved to Orleans, where the young Daguerre grew up. He was educated in the public schools of France and early showed especial aptitude for drawing; producing, it is said, creditable portraits of his parents and friends at the early age of thirteen. At the age of sixteen, he left Orleans to begin life in Paris. There he finally secured employment with Degotti, a flourishing scene painter, and at this the young Daguerre made rapid progress, soon equalling, and finally excelling his master, so that his services were much sought after by the leading theaters. During the years 1816 to 1821 he assisted Pierre Prevost with his panoramic paintings of the cities of Europe and during this time it is probable that he first became acquainted with the camera obscura.

In the production of the large paintings required for the diorama, which he opened in Paris in either 1822 or 1823, Daguerre frequently made use of the camera obscura and it was the remarkable beauty and perfection of the image produced by this instrument that led him to attempt to find a way by which the image might be made permanent. His investigations seem to have begun about 1824. Two years later he received word, probably from Chevalier, an optician from whom he had been in the habit of purchasing the apparatus necessary for his experiments, that the subject was also occupying the attention of a man in the Provinces, Joseph Nicephore Niepce. Daguerre immediately wrote to Niepce suggesting an exchange of secrets, but letters to Niepce received but curt replies until 1827 when Niepce was called to England on account of the serious illness of his brother Claude. Stopping in Paris he met Daguerre and cordial relations were established between the two investigators. On December 5, 1829, the two workers signed an agreement of partnership to continue for ten years, during which time each would work to their mutual advantage. After the death of Niepce in 1833, if not before, Daguerre discarded the method of the elder investigator and started out on different lines. In 1835 he informed Isidore Niepce, who had succeeded to his father's interest in the partnership, that he had reached a certain amount of success, and after two years more of perfecting details, a company was formed to buy out the process for the sum of 200,000 francs. This, however, was a failure and in their extremity the two were forced to appeal to the Government.


A
DAGUERRE
Tombeau de Daguerre.
Cimetière de Bry-sur-Marne
CONSEIL MUNICIPAL DE BRY
A
LOUIS JACQUES MANDÉ
DAGUERRE
NÉ À CORMEILLE EN PARISIS
CONCESSION DE TERRAIN
GRATUITE ET PERPÉTUELLE
DÉLIBÉRATION DU 10 AOUT 18
ICI REPOSE
LOUISE GEORGINE ARROWSMITH
Monument de la Tombe de Daguerre
dans le cimetière de Bry sur Marne

(Courtesy of the Société Française de Photographie)

Fig. 7. Tomb of Daguerre

Daguerre showed specimens, and placed a written account of his process in the hands of Arago, the eminent physicist and astronomer, in January 1839. Arago was impressed with the possibilities of the process and brought the matter to the attention of the Home Minister, to whom Arago's endorsement was sufficient, and on his recommendation the Government awarded Daguerre a life pension of 6,000 francs yearly and to Isidore Niepce one of 4,000, on the condition that the invention be published without patent, this money being paid by France " for the glory of endowing the world of science and of art with one of the most surprising discoveries that honor their native land," to quote the official document. The stipulations were agreed to and in August of the same year (1839) the details of the process were made public before the *Academie des Sciences.* Interest in the process spread rapidly and the inventor made a small fortune in the sale of apparatus for the process. Daguerre died at Petit-sur-Marne in 1851 at the age of sixty-three, having lived to see the science take a large and important place in the affairs of the world. (Fig. 7.)

The Daguerreotype Process.—The Daguerreotype process occupies such an important place in the history of photography that an extended description of the same will not be out of place.

A silver plate, or copper plate covered with silver, is rubbed with tripoli and olive oil and polished with rouge and cotton wool to obtain a highly polished, perfectly smooth, faultless surface. This polished plate is placed with its polished side down in a fuming cabinet (illustrated in Fig. 8) on the bottom of which is a thin layer of iodine crystals. As the iodine evaporates the vapors come in contact with the silver and form silver iodide. After passing through

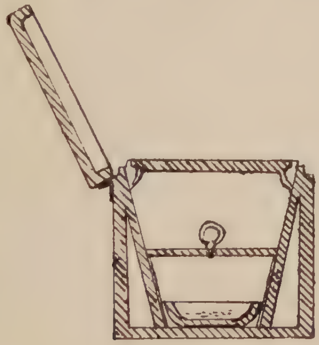


Fig. 8. Fuming Cabinet for the Daguerreotype Process

several successive changes of color, the surface of the silver plate becomes blue and when this stage is reached the plate is removed, placed in the holder, and exposed. Exposure with such a plate for three to four hours produces only a faint impression of the silver iodide and if it had not been for the accidental discovery of the latent image, and the possibility of developing the image by chemical means, Daguerre would have fared no better that his predecessors. Fortunately, however, Daguerre discovered that mercury had the power of bringing out the visible image, so that the exposure necessary was shortened to three or four minutes. The discovery of the latent image, and the possibility of developing the same, was the greatest step towards the realization of practical photography made by Daguerre and one which must forever entitle him to a high place among those who have contributed to the advancement of the science.

Development is conducted in a developing box (illustrated in Fig. 9). The heat of the spirit lamp under the dish of mercury causes the mercury to condense on those parts of the image affected by exposure to light and the image gradually develops as more and more mercury is deposited until a complete reproduction of the original is obtained. For fixing, Daguerre at first used common salt, but soon after the publication of the process Herschel called attention to the use of "hypo" which was immediately adopted.[4]

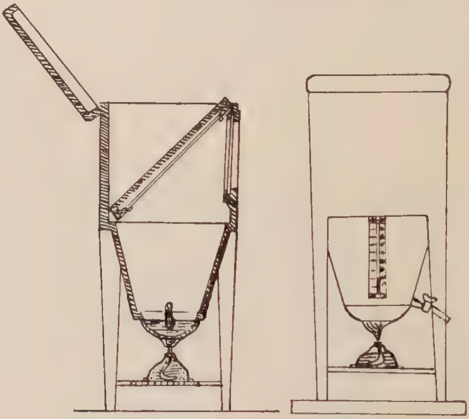


Fig. 9. Developing Box for the Daguerreotype Process

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[4] The chemical reactions involved in the Daguerreotype process cannot be said to be fully understood even at the present time. For a very complete discussion of the same see Waterhouse, "Lessons from the Daguerreotype," *Photo. J.*, 1899, **39**, 60, and 1898, **38**, 45.

Later History of the Daguerreotype.—Daguerre's early plates required an exposure of three to four minutes but the following year (1840) a London science lecturer, Mr. Goddard, discovered the fact that a combination of bromine and iodine was much more sensitive than either alone and a great increase in rapidity was secured, while the time of exposure was reduced by the introduction of the really wonderful Petzval portrait lens by Voigtlander the following year.

The first attempts at portraiture appear to have been made in America. The claims of Dr. J. W. Draper and Robert Cornelius of Philadelphia to have made the first human portrait by photography have been reviewed by L. T. W. in the *British Journal of Photography*. It appears that the portrait of his sister was made by Dr. Draper on March 31, 1840, while Robert Cornelius opened a studio for the Daguerreotype process in Philadelphia on February 18, 1840. As Cornelius must certainly have made experiments before opening a studio professionally it appears that he, and not Draper, was the first to make a portrait by the Daguerreotype process. Draper's portrait, reproduced in Fig. 10, is the first Daguerreotype portrait which is now in existence, none of the results of Cornelius being in existence, so far as known.[5]

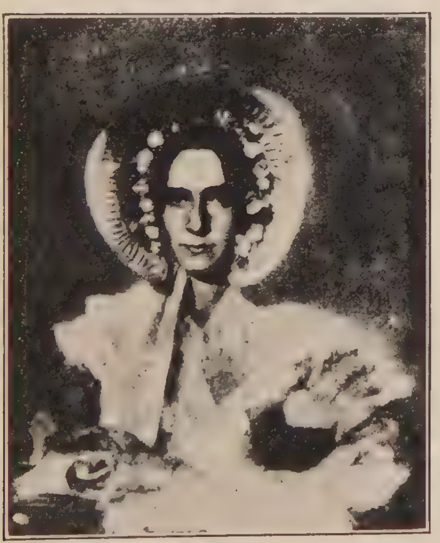

Fig. 10. An Early Daguerreotype Portrait
Often stated to be the first portrait by photography

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[5] *Brit. J. Phot.*, 1920, 67, p. 420.

The Daguerreotype process lasted only about ten years or until the discovery of the wet collodion process by Scott-Archer in 1851. It was almost entirely a portrait process and was not used for landscape and other exterior work to any extent.

The Positive Process of Bayard.—Bayard, one of the founders of the Société Francaise de Photographie, demands a few lines for the positive process which he worked out prior to the announcement of the Daguerreotype. On June 24, 1839, two months before the details of the Daguerreotype process were made public, Bayard exhibited a collection of silver prints made by a method entirely different from that employed by any of the early workers. His process produced a positive print direct and without development. Paper was soaked in a solution of ammonium chloride, dried, floated on silver nitrate and after drying in the dark it was exposed to daylight until completely darkened. Before exposure, it was placed in a solution of potassium iodide and exposed while wet in the camera. The action of light bleached the paper, producing a positive result which was washed and fixed in potassium bromide. The prints were permanent and some are said to be in existence at the present day.

The Life and Early Work of William Henry Fox-Talbot.—William Henry Fox-Talbot (Fig. 11) was born February 11, 1800, at the ancestral home of the Talbots, Lacock Abbey, in Wiltshire. He was of an old and well-established family, the Talbots ranking among the oldest families in England, while his mother was a daughter of the Earl of Ilchester. He was educated at Harrow and Cambridge, leaving the University in 1821 with highest honors, and for two years was a member of parliament, but politics did not interest him and he retired in 1835 to devote the remainder of his life to science. Talbot was a versatile experimentalist; his earlier years were devoted to photography, but in later years he wrote on a wide range of subjects, as spectrum analysis, inscriptions in Egypt, the optical phenomena of crystals and integral calculus, while apparatus in the memorial collection at the Royal Photographic Society speak of his interest in electrical and physical science.

Talbot relates in his *Pencil of Nature*, published in London 1844, that in 1833 he was sketching on the shores of Lake Como in Italy with the camera obscura, but without much success owing to his lack of knowledge of drawing. On his return to England in January the year following he determined to follow up the work of Schulze and

Wedgwood on the action of light on silver salts. His first experiments with silver nitrate and silver chloride were unsuccessful, as the paper was not sufficiently sensitive to light. As a result of many trials, Talbot found that a far greater degree of sensitiveness was obtained with silver chloride if a weak solution of salt was employed, producing what he termed an "imperfect" chloride, which was very much more sensitive to light. Using paper prepared in this manner he was able to readily obtain prints of tracings, leaves, etc., as had Wedgwood and Davy before him and with whose work he was familiar. Talbot, however, was successful where earlier investigators had failed; he found that a solution of common salt would dissolve the unacted-upon salts and render the image permanent. In 1835 he found that the sensitiveness of his paper was greatly increased by giving it successive washings in salt and silver and exposing it while still wet. With paper so prepared he made a picture of his home, Lacock Abbey, using the camera obscura during this same year (1835).

FIG. 11. William Henry Fox-Talbot

The details of Talbot's process, which the inventor styled "*Photogenic Drawing,*" were first made public in a communication to the Royal Institution by Faraday on January 25, 1839, and a week later (January 31, 1839) Talbot himself read a paper on the subject before the Royal Society, of which he was a member. This was Talbot's first paper, and it will be observed that it was published almost eight months before the details of the Daguerreotype process were made public.

The Calotype Process.—The principal work of Talbot, however, was the Calotype process invented by him in 1840. In this process silver iodide was used, the paper being impregnated with silver iodide and immediately before exposure was washed over with a mixture of gallic acid and silver nitrate. After an exposure of about a minute, the image was developed in gallic acid and silver nitrate. Talbot had at last grasped the idea of a *developer* for bringing out the latent image. After fixing and drying, the paper negative was placed over a similar sheet of sensitized paper and exposed to obtain the positive proof. The process was fully described by Talbot before the Royal Society on June 10, 1841.

It is practically certain that in the use of gallic acid to increase the sensitiveness of his paper, and also as a developer, Talbot had been anticipated by an English clergyman, Rev. J. B. Reade, but as the latter did not publish an account of his work, Talbot's discovery was independent and original with him.

Miscellaneous Paper Processes.—The work of Talbot was soon estimated at its true value by a French investigator, Blanquart-Evard. A process devised by him was practically identical with that of Talbot except for the employment of silver chloride instead of iodide. Numerous other processes were invented by various workers, none of which are of more than historical interest, and these we will merely mention, referring those who may desire further information to Robert Hunt's *Treatise on Photography* published in London 1854.

Amphitype—invented by Sir John Herschel.
Anthotype—invented by Sir John Herschel.
Catalysotype—invented by a Dr. Wood.
Chromatype—process using chromic acid.
Chrysotype—invented by Sir John Herschel.
Energiatype—invented by Robert Hunt.
Fluorotype—so called from use of salts of fluoric acid invented by Robert Hunt.

The Introduction of Glass.—Paper is not an ideal medium for negatives owing to its relatively coarse grain, which destroys fine detail, and its opacity, which makes printing slow. To overcome these difficulties Sir John Herschel early attempted to substitute glass, but his process was unsuccessful because he did not recognize that images of sufficient opacity can be obtained only in the presence of albumen, gelatine, or some similar substance, which is capable of attracting and combining with the silver salts. The need of such a substance was recognized by Nièpce de Saint Victor, a nephew of Nicephore, who was responsible in 1847 for a method in which albumen was used. The white of an egg was beaten up with potassium iodide and common salt and the clear liquid poured over a glass plate and allowed to dry. In this state the plates could be kept for some time. Immediately before exposure the plate was dipped in a bath of silver nitrate, which caused the formation of a sensitive silver-chloro-iodide within the pores of the albumen. The plate was exposed either wet or dry and developed in gallic acid. Although no gain in rapidity was made by the albumen process, the results were much clearer and the negatives printed more rapidly, so that the process was immensely popular until the introduction of collodion.

Scott-Archer and the Introduction of Collodion.—In 1847 Schönbein and Bottcher discovered gun cotton and the following year Maynard of Boston showed that the same might be dissolved in a mixture of alcohol and ether to produce a substance of a viscid nature which is termed *collodion.* In 1849 Le Gray, a French investigator, suggested the use of collodion in photography and in a book published in 1850 Robert Bingham, assistant to Faraday, suggests the use of collodion in place of albumen, but the credit for the invention and publication of a workable process employing collodion is due to Frederick Scott-Archer. (Fig. 12.)

The inventor of the collodion process was born at Stortford in 1813 and in early life became a sculptor. He took up the Calotype process in 1847, it is said, for the purpose of making records of his work. We do not know just when he began experimenting with collodion but in 1850 his collodion process was so far advanced that he described it to a few friends, from whom he received some assistance, and the following year the details of the process were published in *The Chemist* for March 1851. Archer appears not to have recognized the value of the process, for he did not patent it, but so complete and perfect was his process that it at once took the place of all other processes, remaining supreme in the field for almost thirty years, and is even to-day unsurpassed for certain branches of work.

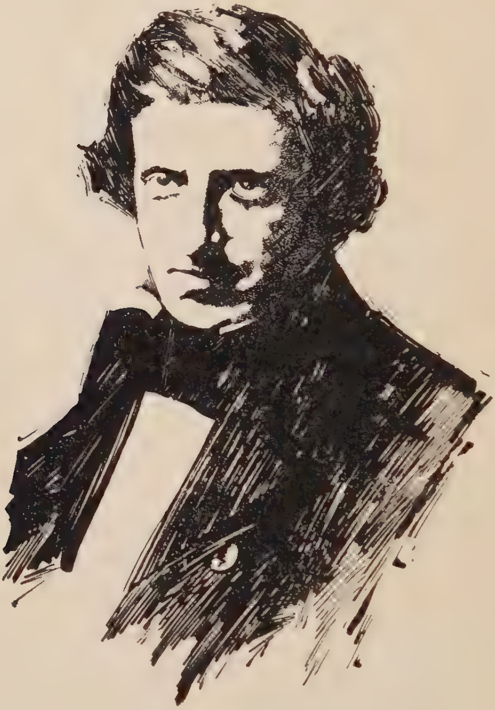

FIG. 12. Frederick Scott-Archer. Drawing from an old print reproduced in J. Werge—*The Evolution of Photography*

Archer was a fertile inventor and made several minor additions to photographic processes which we do not have the space to record, but was a poor business man, and upon his death in May 1857 in practically a state of poverty, the sum of 747 pounds was raised by subscription among friends, and shortly afterwards, Mrs. Archer having passed away, the Government granted the children a pension of fifty pounds a year as "their father was the discoverer of a scientific process of great value to the nation from which he had reaped little or no benefit."

The Collodion Process.—The following is an outline of the collodion process:[6]

1. Prepare pyroxyline by immersing cotton wool in equal parts of nitric and sulphuric acids for fifteen seconds, after which wash thoroughly in water.

2. Dissolve the pyroxyline in a mixture of equal parts of sulphuric ether and absolute alcohol to obtain collodion.

3. Add some soluble iodide, and also a little potassium bromide.

4. Pour on a clean glass plate and allow to set.

5. Take the coated plate into the darkroom and immerse in a bath of silver nitrate (thirty grains to the ounce of water) for a minute. Here a chemical change takes place resulting in the formation of a sensitive silver-bromo-iodide in the pores of the collodion.

6. Place plate in holder and expose.

7. Take plate back to darkroom and develop by pouring over it a solution of water, acetic acid, and pyrogallic acid.

8. Fix by immersion in a bath of sodium thio-sulphate ("hypo").

After the introduction of collodion, photography for the first time became really popular. Out of this newborn interest in the subject arose several institutions which were to stand until the present time and to exercise a favorable influence on the further developments of the science. The Royal Photographic Society was founded in 1853 as the Photographic Society of London, and the following year the Société Francaise de Photographie was organized at Paris. In 1854 the well-known *British Journal of Photography* was established as a monthly, becoming a weekly in 1859, while the year previous had witnessed the birth of the *Photographic News.*

Inconveniences of the Collodion Process.—While a notable advance upon all previous processes, the collodion process was subject to several grave objections. It is absolutely necessary that the plates be exposed and developed as quickly as possible after their preparation before the surface has had time to dry. For this reason the wet plate process, while well adapted to the studio, is not so suitable for landscape work, or for general amateur use. A heavy equipment had to be carried in the form of a tent, sensitizing bath, developing trays, fixing and developing solutions, and a plentiful supply of pure water. Some idea of the inconveniences of outdoor photography with the collodion process may be had from Fig. 13 and Fig. 14; the former shows the photographer " en route " with his outfit and the latter the outfit in use in the field. Sometimes the outfit was arranged to be carried on a cart drawn by a donkey, an example of which is in the museum of the Royal Photographic Society of Great Britain. Furthermore if the exposure was a long one, as might easily be the case with interiors where exposures run to several hours, the surface of the plate dried and the picture was spoiled. Lastly in cold weather the sensitizing bath, solutions, water supply and *plates* would freeze, so that photography in winter, or in cold climates, was well nigh impossible.

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[6] For a full description and formula see: *Wet Collodion Photography,* by C. W. Gamble; *The Wet Collodion Process,* Arthur Payne.

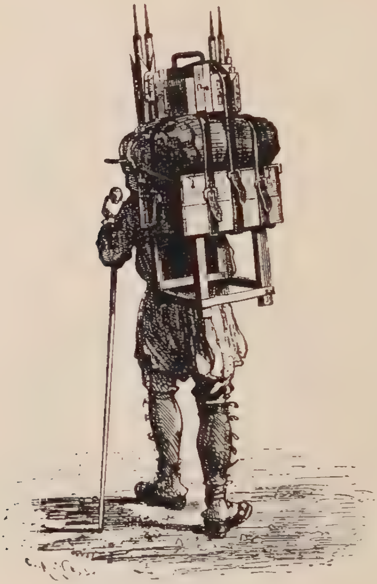

Fig. 13. The Wet Collodion Process in the Field
(From an old manual)

Despite these obvious drawbacks, some of the work of this period ranks with the best that photography has produced. The work of Rejlander, the portraits of Solomon, Mrs. Cameron, and much of the famous work of H. P. Robinson were all done with collodion, and will ever remain as notable tributes to the enthusiasm and energy of these untiring workers.

Modifications of the Collodion Process.—To overcome the defects of the collodion process John Spiller and William Crookes in 1854[7] proposed the use of a deliquescent salt, such as magnesium nitrate, to keep the collodion moist and allow it to be kept several hours before use. The same year George Shadbolt and Maxwell-Lyte advised the use of honey and grape sugar to prevent evaporation. The most successful method, however, was the collodio-albumen process devised by Taupenot in 1855.[8] In this process the plate after having been coated with iodized collodion in the usual manner was then flowed with albumen and allowed to dry, when it was immersed in a bath of silver nitrate, washed and dried. The plates so prepared were very slow, about six times slower than ordinary collodion, but would keep well and were rather extensively used by landscape workers.

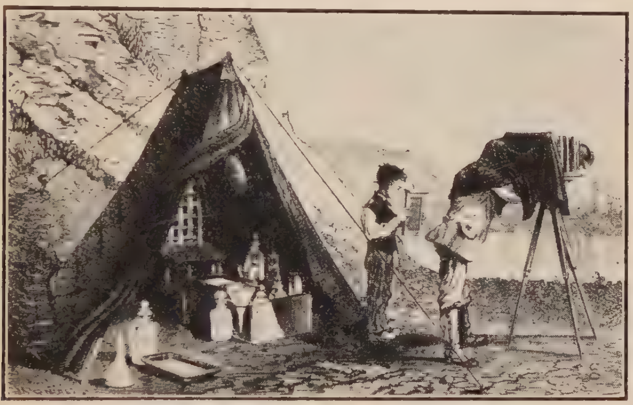

FIG. 14. Portable Laboratory for Field Use with Wet Collodion

In 1855 Dr. Hill Norris of Birmingham described a process[9] in which the plates were first washed in water and then immersed in pyrogallic acid, after which they were dried and kept until wanted. The following year he took out a patent for a collodio-gelatine process, the sensitive collodion plates being covered with a solution of gelatine in order to prevent its condensation on drying and to keep in a sensitive state. Dry plates so prepared were placed on the market and large numbers were sold between 1855–1866.

Among other processes having as their object the production of dry plates we may mention the tannin process of Major Russel, introduced in 1861; the albumen-beer process of Capt. Abney, 1874; the resin process of the Abbé Desprats and the oxymel process of Llewelyn.

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[7] *Philosophical Magazine.*

[8] *La Lumiere,* Sept. 8, 1855.

[9] *Jour. Phot. Soc. of London* (R. P. S.), May 1855.

The Introduction of Collodion Emulsion.—The term *emulsion* is properly applied to a liquid holding another immersable liquid in suspension in an extremely fine state of division. In photography the term is a misnomer for a mechanical suspension of a solid sensitive salt of silver in a finely divided state in a substance such as collodion, albumen or gelatine. While Gaudin, and Dixon and Fry[10] had met with some success in the preparation of a workable collodion emulsion, it remained for Sayce and Bolton to work out the first satisfactory method for the preparation of a suitable collodion emulsion for photographic purposes in 1864.[11] These workers added nitrate of silver to a bromized collodion thus producing a sensitive bromo-silver collodion. Plates coated with this emulsion were flowed over with tannin and dried. Later improvements consisted in increasing the amount of silver and the addition of tannin directly to the emulsion. Many others added suggestions of importance, among whom may be mentioned Carey Lea, Col. Stuart Wortley, George Dawson, Thos. Sutton and W. J. Stillman.

For several years after the introduction of collodion emulsion the excess silver salts were removed by washing the plates after coating. In 1871 Sutton suggested the use of a "corrected" emulsion in which the proportions of bromide and silver were so adjusted as to leave neither in excess, but because of the practical difficulties in determining the proper proportions the method is not satisfactory.

In 1874, Bolton showed that the emulsion might be washed *before* the plates were coated[12] and the following year Rev. Canon Beechey described[13] a similar method using pyrogallic acid as a preservative. This method was perhaps the most reliable and uniform method of preparing collodion dry plates, and plates so prepared became an article of commerce. While not so rapid as ordinary wet collodion, the Beechey plates were sufficiently rapid for exterior work, requiring an exposure of from 30 to 60 seconds with a diaphragm equivalent to F/16.

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[10] *La Lumiere,* Aug. 1853; *Photo. News,* 1861, p. 193.

[11] *Brit. J. Phot.,* September 9, 1864.

[12] *Brit. J. Phot.,* Jan. 16, 1874.

[13] *Brit. J. Phot.,* Oct. 1, 1875. Harrison, *History and Handbook of Photography,* Appendix.

The Introduction of Gelatino-Bromide Emulsion.—The first record of the application of gelatine to photography was the unsuccessful attempt of Niepce de Saint Victor in 1847 as a vehicle for holding silver iodide on glass plates.

In 1853, Gaudin gave a formula for what we would now term gelatino-iodide emulsion but his method was not practical. His experiments, however, led him to recognize the fact that bromide of silver is more sensitive in combination with gelatine than iodide of silver.

The use of gelatine as a preservative of wet collodion by Norris in 1856 we have already noticed under collodion emulsion.

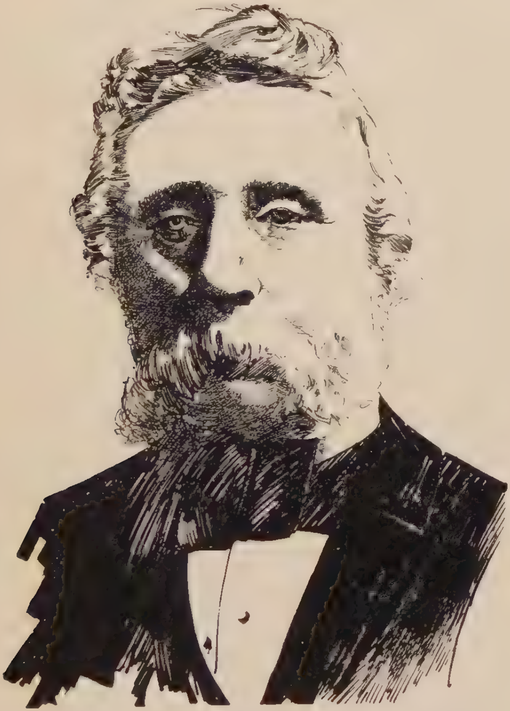

FIG. 15. Dr. Richard Leach Maddox

In 1868, W. H. Harrison [14] published the results of his experiments on the emulsification of silver bromide in gelatine but his method was of no practical value, the principal significance of his work being the use of an alkaline developer.

While Le Gray, Smith, Harrison and Sutton had either suggested the use of, or had experimented with gelatine, it is to Dr. R. L. Maddox (Fig. 15), an English amateur, that we owe the first really workable method of preparing gelatino-bromide emulsions. His method was fully described in an article in the *British Journal of Photography* for September 8, 1871, under the following title: "An Experiment with Gelatino-Bromide." The introduction of gelatine pointed the way to plates of a higher degree of sensitiveness than had been possible with collodion, so that while the process of Dr. Maddox was not revolutionary and complete in itself as was that of Scott-Archer, it marks an epoch in the development of photography.

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[14] *Brit. J. Phot.*, Jan. 17, 1868.

In the method described by Dr. Maddox, silver bromide was formed in the presence of gelatine, the emulsion containing an excess of silver and a small amount of *aqua regia*. *Without further treatment* the emulsion was coated on glass plates, dried, and exposed. Development was conducted with pyrogallic acid and intensification with pyro and silver nitrate followed.

With our present knowledge it is not hard to see why Dr. Maddox did not meet with complete success. He does not seem to have realized the necessity for washing the emulsion so as to remove the excess silver salts, although this was regularly done with collodion emulsion processes. Consequently the presence of the excess salts of silver and the nitric acid from the *aqua regia* acted as a restrainer and made the plates very slow.

It is noteworthy that Maddox had some idea of the ripening processes which have meant so much to the development of the gelatino-bromide process, as he tried to increase the sensitiveness of his plates by fuming with ammonia (a method that had been previously applied to albumen paper) but without success.

Very little attention was paid to the work of Maddox at the time, but two years later Burgess advertised a gelatino-bromide emulsion in the English photographic journals.[15] The method employed by Mr. Burgess in the preparation of his emulsion was never published and did not prove to be a commercial success, but he was the first to show that excellent results could be obtained on gelatine, and that gelatino-bromide emulsion could be produced which was equal in sensitiveness to wet collodion.

Improvements in the Gelatino-Bromide Process.—The same year that Burgess introduced his emulsion commercially, King and Johnson described independently of each other two methods for removing the excess of silver salts from the emulsion. King's method consisted in placing the emulsion in a container of vegetable parchment or bladder; the whole being immersed in a large vessel of water, under which circumstances the soluble salts pass outwards through the parchment into the water. Johnson's process, described in the same issue of the *British Journal of Photography,*[16] advised the use of an excess of soluble bromide—a point of great importance—and plain washing of the shredded emulsion in running water to eliminate the excess salts. On account of its simplicity and effectiveness this method has been generally adopted.

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[15] July 18, 1873.

In November of the same year Richard Kennett, an amateur residing in London, took out a patent[17] for a method which he discovered of preserving the emulsion and the following month announced his "sensitive pellicle" which was nothing more than a dried, sensitive gelatino-bromide emulsion. The pellicle was quite successful and remained on the market for about ten years.

In 1874 Bolton suggested that only a small part of the gelatine be used for preparing the emulsion, the rest being added afterwards—a procedure which later proved of great value when the effect of heat on the emulsion was discovered. The same year Stas observed that several forms of silver bromide are possible and that heating formed the most sensitive compound.[18] The same year (1874) gelatine plates first appeared on the market, manufactured by the Liverpool Dry Plate Co. Bromide paper appeared at the same time.

In 1878 Bennett showed that the sensitiveness of gelatino-bromide emulsion might be greatly increased by keeping the emulsion at a temperature of 90 degrees Fahr. for five to seven days.[19] This added a great impetus to the development of gelatino-bromide emulsion and another firm of dry plate makers took the field—Messrs. Wratten and Wainwright.

The prolonged stewing of the emulsion at 90 degrees, however, was not only troublesome but led to trouble owing to the partial decomposition of the gelatine, so Mansfield announced in 1879[20] that this long and troublesome process could be avoided by forming the bromide of silver in a weak solution of gelatine which was then *boiled*

[16] November 14, 1873.

[17] B. P. No. 3782 of November 20, 1873.

[18] *Annales de Chimie,* Fifth Series, vol. III, p. 289.

[19] *Brit. J. Phot.,* March 29, 1879.

[20] *Brit. J. Phot.,* August 22, 1879.

for ten to fifteen minutes, the remainder of the gelatine being added when the solution had cooled. Emulsification in a portion of the gelatine, the remainder being added after digestion, was a repetition of the advice given by Bolton in 1874.

In May 1879 Captain Abney showed that a good emulsion might be formed by precipitating silver bromide in glycerine, the precipitate after two or three washings with water being mixed with the proper amount of gelatine to form the emulsion. The object of this method was to save the trouble of washing the emulsion in order to eliminate the excess silver salts as required in the usual process.

In 1877 Johnson described the use of an aqueous solution of ammonia for the ripening of gelatino-bromide emulsion.[21] Not much attention seems to have been paid to this communication, however, and it was not until Monkhoven in 1879[22] suggested that the increased sensitivity of the emulsion produced by prolonged heating might be due to a change in the molecular state of the silver bromide along the lines of the work of Stas and showed that silver bromide might be changed from the ordinary to the most sensitive green state by treatment with ammonia that much interest was taken in the subject. The following year Eder investigated the matter very thoroughly and perfected a process using ammoniacal silver oxide and later discovered the advantageous influence of ammonia and ammonium carbonate on the ripening of gelatino-bromide emulsion in the cold.[23] The following year Abney showed the advantage to be gained from the use of a small amount of iodide in gelatine emulsions. The addition of iodide at first reduced the speed of the emulsion to a certain extent, but gave clearer negatives having greater density. A small percentage of iodide is used in nearly all modern plates.

In the meantime, the spread of gelatino-bromide emulsion had been exceedingly rapid and by 1882 gelatine emulsion had almost completely displaced collodion, except for some few specialized purposes.

The Introduction of Film.—The introduction of the dry plate made unnecessary the dark tent, the nitrate of silver bath, and other inconveniences of the wet-collodion process, and resulted in a large increase in the number of amateurs. The next step in the simplification and consequently the popularization of photography was the introduction in 1884 of the stripping film of Eastman and Walker of Rochester,

[21] *Brit. J. Phot. Almanac,* 1877, p. 95.

[22] *Brit. J. Phot.,* October 17, 1879.

[23] *Sitzungsber. Akad. Wiss, Wien,* 1880, 81, 679.

N. Y. This was a gelatino-bromide emulsion coated on paper in such a way that after development and fixing, the image could be stripped from the paper support and dried on glass. This film was supplied in rolls and a roll holder was provided to adapt it to the plate cameras then in common use. From the standpoint of the general public, this was a great advance but the process was still intricate and difficult for the amateur on account of the delicate handling demanded in transferring the image from paper to the final glass support. Four years later the stripping film with its paper base gave way to a transparent base of nitrocellulose. The discovery of a new base of the sensitive emulsion equal in every way to glass and with the added advantages of being flexible, light and unbreakable combined with the introduction of the daylight loading roll film camera (1891) brought photography within the reach of all.

Development of Printing Processes with Silver Salts.—The development of positive printing processes begins with Fox-Talbot's Calotype process in 1841, although it was not until after the invention of the collodion process that much progress was made in this line.

For printing from his early negatives, Fox-Talbot employed what we to-day term the salted paper process. Paper of suitable surface and texture is immersed in a weak solution of salt, after which it is dried, and in this state it may be kept indefinitely. Just before use, it is sensitized in silver nitrate and dried, after which it is exposed to daylight under the negative to be reproduced. When the image is sufficiently dark, the print is removed and toned in a solution of gold chloride which is followed by fixing in a bath of "hypo." Talbot's early prints, however, were not toned, as gold toning does not seem to date back further than 1849. We will have more to say regarding plain salted paper later on as it is to some extent in use at the present time.

Le Gray appears to have been the first to suggest coating the paper with albumen before sensitizing in order to obtain a higher gloss, although Fox-Talbot is often credited with the same. Albumen paper was quite popular and practically the only paper used from 1860–1885.

A method of using collodion in place of albumen was described by G. Wharton Simpson in 1864[24] and collodio-chloride of silver papers were introduced commercially by Obernetter of Munich two years later, but the process did not attract much attention until the introduction of a much improved product by Liesegang of Düsseldorf in 1886.

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[24] *Photographic Yearbook*, 1865, p. 63.

Gelatino-chloride papers appear to have been first employed by Palmer and Smith as early as 1866, but no details were published. Full details for the preparation and use of gelatino-chloride papers were published by Abney [25] in 1882 and, papers of this type were introduced commercially two years later by Obernetter of Munich and a few years later by Liesegang of Düsseldorf and Ilford of London.

The above papers are all members of the class known as printing-out-papers; that is, they produce a visible image upon exposure and there is no after development. The now popular developing papers appear to have had their prototype in a process used by Blanquart-Evrard in 1851, but it was not until 1874, after paper coated with gelatino-bromide emulsion had been introduced by the Liverpool Dry Plate Company, that developing papers made any headway. In 1880 Morgan and Kidd established a factory at Richmond (England) and in 1885 Eastman of Rochester introduced the machine coating of paper in the roll with gelatino-bromide emulsion after which gelatino-bromide paper began to assume importance as a printing process.

Directions for the preparation and use of emulsions of silver chloride for positive printing were published by Eder and Pizzighelli in 1881.[26] The first papers of this type were introduced commercially by Dr. E. Just of Vienna in 1883 and shortly afterward in England by Edwards and Warnerke but "Velox" introduced in American by the Nepera Chemical Company from the formula of Dr. Leo Baekeland was the first to achieve wide popularity. Its successful introduction paved the way for a large number of similar papers in all important countries.

The use of gelatino-chloro-bromide emulsions for positive printing was introduced also by Eder and Pizzighelli in 1883.[27] Chloro-bromide emulsions are especially adapted to the production of warm-tone images and papers of this class are widely employed for portrait work at the present time. Many lantern slide plates and positive cinematograph films are also coated with emulsions of this type.

Platinum Printing Processes.—In 1832 Herschel discovered that light had a reducing action on platinum compounds, especially in the presence of an organic salt such as ferrous oxalate. Hunt in 1854 tried to turn this to account by coating paper with ferric oxalate and platinic chloride, but he failed to realize an essential point, the two salts must be in solution before the reaction can take place. It is to William Willis Jr. that we owe the platinum process in its present form. He took out his first patent in 1873, a second in 1878 and the last in 1880. Under the last patent, paper is coated with a mixture of potassium chloroplatinite and ferric oxalate. This is exposed under the negative until the image is sufficiently printed when it is removed and placed in a solution of potassium oxalate, in which the reduced iron salt is soluble, and as it is dissolved by the oxalate it attacks the platinum compound and reduces it to the metallic state. After immersion in several baths of hydrochloric acid to remove the iron salts which remain, the print is washed and dried.

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[25] *Phot. News*, 1882, **24**, 300.

[26] *Die Photographie mit Chlorsilbergelatine mit Chemischer Entwicklung*, Vienna, 1881.

[27] *Phot. News*, 1883, **25**, 98.

Sensitiveness of Chromic Compounds and Bichromated Colloids.—The first to observe the sensitiveness of chromium compounds to light appears to have been Mungo Ponton, an Englishman, who in 1839 discovered that paper soaked in a bichromate and dried was sensitive to light. The following year Becquerel discovered that when the paper was sized with starch it became more sensitive and he decided that the sensitiveness of the chromium compound was due to the presence of organic substances used for sizing the paper. In 1852 Fox-Talbot found that when bichromate is mixed with gelatine and exposed to light the gelatine is rendered insoluble. In 1855 Alphonse Poitevin discovered that if a colored substance be added to gelatine, sensitized with potassium bichromate, and exposed to light under a negative, the unaffected parts might be washed away leaving an image formed by the colored substance held in the insoluble gelatine formed as a result of the action of light. This was the foundation of the carbon and gum-bichromate processes. Poitevin also discovered that a bichromated gelatine film when exposed to light and allowed to swell in water would take a greasy ink on the exposed portions but not on the unexposed portions. From this he developed a process of photomechanical printing known as collotype and at a later date the processes of oil and bromoil, based on the same principle, were brought out by others. Poitevin may thus be termed the father of printing processes employing bichromated colloids.

The Development of the Carbon and Gum-bichromate Process.—

In 1858 John Pouncy of Dorchester, England, was granted a patent for a carbon process based upon the same principles as that of Poitevin. His method consisted in brushing over paper a mixture of bichromatized gelatine and carbon: the paper after drying being exposed under the negative and developed in water. His results were far from satisfactory, however, because the half tones were lacking.

The same year the Abbe Laborde showed the reason for this saying: "In the sensitive film, however thin it may be, two distinct surfaces must be recognized, an outer and an inner which is in contact with the paper. The action of the light commences on the outer surface. In the washing, therefore, the half tones loose their hold on the paper and are washed away."

The same year J. C. Burnett, Blair and Schouwaloff to overcome this defect suggested the expedient of exposing from the back of the paper, but in 1860 Fargier in France showed that the best way was to coat the exposed film with collodion, then transfer it to glass and then wash away the soluble gelatine from the back. This method, however, was too complicated for general use.

In 1864 J. W. Swan patented carbon tissue, which is simply paper coated with gelatine and pigment, which, after sensitizing in bichromate, is exposed under the negative and transferred before development to another support. The tissue backing is then stripped off leaving the pigmented gelatine on the new support. Development is effected by washing away the soluble gelatine in water. This was the first really practical process of pigment printing in which the pigment is incorporated with the bichromated colloid before exposure.

The gum-bichromate process, now so popular among pictorialists of a certain class, is nothing more than Pouncy's carbon process which he described before a meeting of the Photographic Society of London in 1858. It was brought to the front about 1895, largely as the result of the work of Robert Demachy, Ch. Puyo and other French pictorialists. Abroad, it passed out upon the advent of the oil and bromoil processes but in America it has held its ground and is still popular in many quarters.

In 1873 Marion [28] found that a sheet of paper immersed in bichromate and exposed to light so as to produce a faint image will transfer its image to a sheet of pigmented carbon tissue when the two are placed in contact with one another. This is due to the fact that there is left in the image some chromate of chromium, the salt formed as

[28] *Brit. J. Phot.*, 1873, p. 342.

a result of the action of light on the bichromate, and this diffuses into the pigmented tissue and renders it insoluble just as if it had been exposed to light. Manly in 1899 introduced [29] a process of pigment printing based upon this principle under the name of *ozotype*. This failed to catch on, however, and in 1905 the same worker introduced [30] his *ozobrome* process. In this a sheet of ordinary carbon tissue was soaked in a solution containing potassium bichromate, potassium ferricyanide and potassium bromide. It was then placed in contact with an ordinary bromide print which had been previously soaked in water to become limp.

After being kept under pressure for several minutes the carbon tissue was stripped from the bromide print, squeezed to its final support and developed as usual. The bromide print thus takes the place of the negative, so that an enlarged negative is not required when prints larger than the original negative are desired, nor is daylight necessary at any stage. Ozobrome for a while was quite popular but finally fell into disuse. It was revived, however, in an improved form by H. F. Farmer in 1919 under the name *carbro* and in its improved form has become so popular that it is again bringing carbon printing back to the attention of amateurs and professionals and may eventually supersede carbon, except where critical definition is required.

The Development of the Oil and Bromoil and Powder Processes.— A second process was worked out and patented by Poitevin in which a bichromated gelatine film without pigment was exposed under a negative. This gelatine film upon exposure to light under the negative became more or less insoluble in various portions according to the gradations of the negative. When immersed in water, the soluble gelatine absorbs water and becomes so charged with water that it will repel a greasy ink, while the shadows, being insoluble, do not absorb water and will accept the ink. Accordingly when a roller charged with greasy ink is passed over the paint, an image is formed in greasy ink which adheres to the shadows but not to the highlights of the print. This process was the forerunner of a number of photomechanical processes, which are beyond the scope of this work, and the oil, bromoil and powder processes.

Poitevin's patent of 1855 is not very explicit, but in 1858 Asser was granted a patent for a process based upon the same principle and in which very precise directions were given.

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[29] British Patent No. 10,026/1899.

[30] British Patent 17,007/1905.

Two years previously the Duc de Luynes through the Societe Francoise de Photographie had offered a prize of 10,000 francs to the person discovering a process by which absolutely permanent prints might be produced. The President of the Societe, *M.* Regnault, the famous chemist, in announcing the offer called attention to the permanency of carbon and suggested that experiments be conducted with a view to obtaining prints in carbon. Two Frenchmen, Garnier and Salmon, starting from Poitevin's patent of 1895 worked out a process in which the bichromated gelatine was exposed to light under the negative, then soaked in water and pure finely divided carbon dusted over it. The carbon adheres only to the unexposed parts and in this way an image is secured. This was the beginning of the so-called *powder processes.*

Rawlings' process of oil printing (1904) is actually little more than a modification of the process covered by Poitevin's patent of 1855. Rawlings advised the use of brushes rather than a roller for applying the ink, thus making possible the control of the various tones of the print by varying the amount of ink deposited. This feature served to attract various workers who wished to have a ready means of altering the tone values of their prints and the process rapidly gained in popularity among pictorialists.

In 1889 Howard Farmer found that when a gelatine film containing finely divided silver, as in a negative or positive, is immersed in a bichromate, the gelatine in contact with the metallic silver is rendered insoluble exactly as though it had been exposed to light in these portions. Upon this property of a bichromated colloid is based the bromoil process The first suggestion of the rationale of this process is due to E. J. Wall.[31] It was taken up and worked out practically by C. Welborne Piper.[32]

Conclusion.—With this our history of the development of photography must be brought to a close. Many are the names and processes which we have been compelled to barely mention and not a few have been omitted altogether, while all have been treated in outline only, so that only a general idea of their essentials has been gained. It is hoped, however, that this short account has been of sufficient interest to encourage the student to follow up the subject by outside reading in larger and more comprehensive works and to assist in this worthy end a short list of the leading historical works on photography is appended.

[31] *Phot. News,* 1907, **51**, 299.

[32] *Phot. News,* Aug. 16, 1907.

GENERAL REFERENCE WORKS

BROTHERS—A Manual of Photography. London, 1899.
BROWN—Who Discovered Photography? Photo-Miniature, No. 60. 1903.
COLSEN—Memoires des Createurs des Photographie. Paris.
EDER—Geschichte der Photographie. Halle a/S.
EDER—Johann Heinrich Schulze. 1917.
FOUQUÉ—Sur l'Invention de la Photographie. Paris, 1867.
HARRISON—The History of Photography. London and New York, 1885.
LITCHFIELD—Tom Wedgwood, The First Photographer. London.
POTONNIÉE—Histoire de la Découverte de la Photographie. Paris, 1925.
SCHIENDEL—Geschichte der Photographie.
SHEPPERLEY—A History of Photography. London, 1929.
TISSANDIER—History and Handbook of Photography. London, 1874.
WERGE—The Evolution of Photography.

CHAPTER II

THE CAMERA AND DARKROOM

I. The Camera

The Box Camera.—The simplest and the cheapest possible camera which you can purchase is one of the box form. Such cameras are cheap because they are made in large quantities by machinery and because they do not have the capabilities and adjustments of more expensive models. Naturally they are more limited in their scope and cannot be used for a wide range of work. However, since they are simple and easily operated they form an excellent camera for the beginner, who has not yet become familiar with the various adjustments which render the more expensive instrument capable of handling a wide range of subjects more efficiently.

Box cameras are supplied in several sizes from 1⅝ x 2½ to 3¼ x 5½ inches and in both roll film, pack and plate models, although the last named have practically disappeared from the commercial market. On account of the greater bulk of the camera the smaller sizes are most popular and since the roll film or film pack models are lighter and more convenient to use they have practically superseded plate cameras of this type. Box cameras are generally fitted with cheap single achromatic lenses which cannot be used at a larger aperture than F/16. In bright light, from 8 to 3 o'clock, snapshots may be made if the subject is open and not in shadow. Under other conditions the camera must be placed on a firm support and a time exposure given. Since the positions of both lens and film are fixed it is impossible to focus and the lens is so placed that all objects from infinity to within 10 to 15 feet of the camera are defined with satisfactory, if not critical sharpness. This avoids one of the difficulties of the beginner and hence such cameras, under the proper conditions of light, give good results with the minimum of trouble and skill on the part of the user.

The Miniature Camera.—The miniature camera, or V.P. camera as sometimes termed, ranges in size from 4½ x 6 cm. (1.77 x 2.36 inches) to 6½ x 9 cm. (2.56 x 3.5 inches), is more expensive, and is designed to be fitted for a wide range of serious work with the minimum of inconvenience to the owner when not in use. The particular feature of these cameras is their portability. They are small and light, so that they may be carried in an ordinary pocket without annoyance and brought into use quickly and with the minimum of effort when desired for use. At the same time such cameras are capable of really serious work, when they are handled with skill, since when fitted with good lenses the small negatives enlarge readily to medium sizes. A typical example of an instrument of this type is shown in Fig. 16.

When purchasing a camera of this kind it is well to remember that although they are rather expensive it is well to get the best and especially to secure a good lens since good sharp definition will be required for subsequent enlargement, while a large aperture will enable snapshots to be made when otherwise impossible. Another important thing to examine is the soundness of construction. While a certain sacrifice in stability is necessary in order to prevent undue weight and size it is desirable that the instrument be sufficiently strong to withstand long-continued usage.

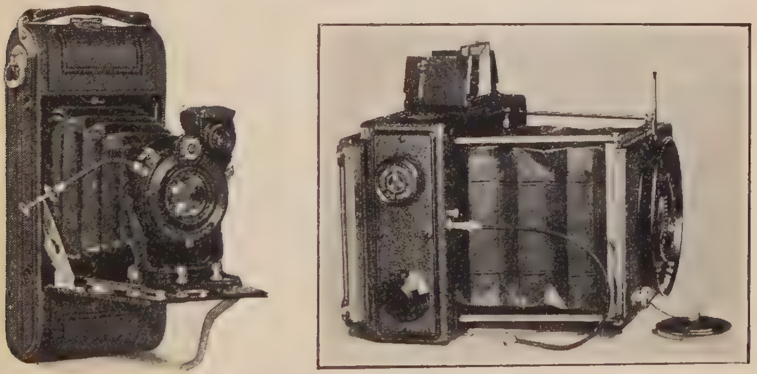


Fig. 16. Typical Miniature Camera for Plates and for Roll Film

Many cameras of this type are rather overloaded with adjustments and movements, which are useful at certain times but are more often simply a hindrance to fast work. In the opinion of the writer the following are the most important features of a miniature camera:

1. Body of aluminum or better Duraluminum.
2. A platform so that the lens is covered when the camera is folded.

3. When opened the front should lock with the lens in focus for objects at a medium distance, say 15 to 30 feet.

4. Further focussing should be provided for with either a lever or pinion, conveniently located.

5. The focussing scale, shutter speed and diaphragm scales should all be visible from the top of the camera so that any adjustments may be made while the subject is being followed in the finder. In the case of cameras designed for use with direct view finders the shutter and diaphragm scales should be visible from the viewpoint of the eye when following the subject in the finder.

6. The finder should be placed as close as possible to the lens in order that the correspondence between the two may be as perfect as possible.

7. The lens should be a high-grade anastigmat, with a large aperture, as *F*/4.5 or larger, in a shutter with a wide range of speeds from one second to 1/200.

The advantages as regards convenience certainly lie with the miniature camera using roll film but many of the disadvantages of plates are removed when small sizes are used. Thus weight becomes negligible, and the only remaining difficulties are those of loading and unloading plate-holders, while the advantages of focussing and selection of particular plates for different purposes are valuable to the serious worker. At the same time when facilities are lacking for the use of plates, film packs may be used in an adapter which may be loaded or unloaded in daylight and focussing done just as with plates. Film packs thus offer the same advantages as both films and plates.

In the last few years a new class of miniature camera using standard 35 mm. motion picture film has become prominent. The picture area in the case of these cameras ranges from the standard motion picture size, ¾ x 1 inch (18 x 24 mm.) to double this size, or 1 x 1½ inches (24 x 36 mm.). When constructed with a high degree of precision and fitted with the better grades of anastigmat lenses, these cameras become very capable instruments. The short focus objectives, with which they are fitted, have great depth of focus and thus render practical the use of much larger apertures than on larger cameras which must be fitted with lenses of longer focal length. With good optical definition, the fine grain of commercial motion picture film allows of considerable enlargement without loss of definition.

Folding Hand Cameras.—Folding hand cameras are made in sizes from 2¼ x 3¼ to 4 x 5 inches (or from 6.5 x 9 to 9 x 12 cm.) in both film and plate models. There is without doubt a greater demand for this class of instrument than any other—a fact which is evident from the wide range of models provided by the various manufacturers. For one thing, the contact prints are sufficiently large to satisfy the requirements of the average amateur, while the instrument itself, although less portable than the miniature camera, is easily slipped into the coat pocket or slung over the shoulder by means of a leather strap.

Roll film models of this class call for the barest mention since they are the cameras in general use by the larger body of amateurs. They are ideally fitted to the needs of most amateurs for whom the camera is only a method of keeping a record of their happy experiences on trips and during vacation. For serious photographic work of a general nature they are not so well adapted since they are not provided with means of focussing on the ground-glass, and consequently cannot be used for copying and work of a similar nature. For this reason many prefer to purchase one of the light plate cameras and use film-pack whenever the advantages of lightness and daylight loading are important.

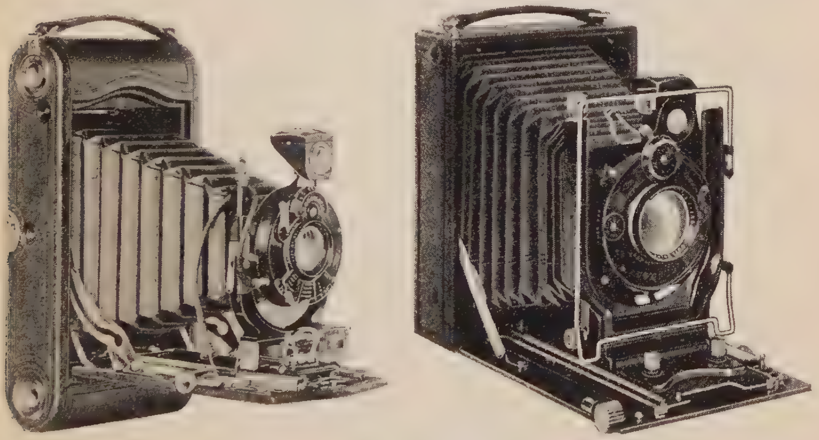


Fig. 17. Hand Cameras for Plates and for Roll Film

The more expensive plate cameras of this class are exceedingly versatile instruments and are capable of doing almost anything that the average photographer is likely to demand. They are fitted with reversible backs so that pictures may be made either vertically or horizontally without turning the camera on its side and many of them have a long bellows which enables them to be used for copying and photographing small objects. In addition, the long extension permits the use of long-focus lenses, which for portraiture and certain kinds of landscape work are very desirable.

Some of these cameras are also fitted with a swing back which enables the plate to be kept in a vertical position while the bed of the camera is tilted upward in order to include the whole of a tall object on the plate. Various other features are supplied on the different instruments such as rising and falling front, wide angle bed for using wide angle lenses, and sometimes sliding fronts are fitted. Since these cameras are always fitted with a finder and focussing scale they may be either held in the hand or placed upon a tripod. They are thus suitable for both the most exacting work and at the same time may be used as a hand camera whenever desired. There is little question that this is the most efficient instrument for really serious photographic work which the amateur can buy. Typical examples of hand cameras for both plates and film are shown in Fig. 17.

The Professional Camera.—The view and studio cameras in general use by the professional photographer do not differ greatly from the folding plate camera which we have just described. They are usually more substantial and consequently more bulky, while they are of larger size—the ordinary sizes being 5 x 7, 7 x 11, 8 x 10 and 11 x 14 inches. In addition to greater stability, the movements fitted to professional cameras have a wider range of adjustment than those of the more compact hand camera, which is not intended for such a broad range of work. Not only are the adjustments fitted to the professional camera of greater latitude, but there are, in the better ones, adjustments which are not found on the hand camera. These provide the extreme range of movement necessary in technical photography. The lens board is also larger so that long focus lenses of large aperture may be accommodated. In addition there is provision for focussing from either the back or the front—a valuable feature when wide angle lenses are in use, since in this case focussing may be done from behind and there is no danger of a part of the camera bed appearing in the picture. Some cameras of this type known as banquet cameras, made for such work as their name indicates, have an arrangement by which the lens may be tilted downward while keeping the plate vertical, so that large groups may be photographed from above with the minimum of distortion (Fig. 18).

The studio camera is in general similar to the view camera except that it is much heavier and larger, the rising front is dispensed with as is also front focussing. The lens board is larger so that the large bulky portrait or anastigmat lenses of long focus and large aperture may be readily accommodated.

The Reflex Camera.—The principle of the reflex camera requires a word of explanation since it is radically different from any of the cameras which we have already described. Fig. 19 shows a typical reflex in cross section. The rays of light from the object pass through the lens and are reflected by the mirror to the focussing screen at the top of the camera, where the image is of course in its normal unreversed position, i.e. right side up. Behind the mirror is the focal plane shutter and behind this the sensitive plate. The focal plane shutter consists of a long opaque curtain with apertures of varying lengths, any one of which may be made to pass across the front of the plate at a high speed. When the image has been focussed on the ground-glass and the exposure lever is depressed the mirror swings up out of the way and forms a light-tight joint with the focussing screen. As soon as the mirror reaches this position it automatically operates the shutter. Thus two distinct operations are performed in the interval between the action of the exposure lever and the actual exposure. First the mirror is released and swings up, and then an aperture in the curtain of the focal plane shutter passes over the plate and makes the exposure. However, in a well-made reflex the mirror and shutter are so well coördinated that the time interval is not more than 1/10 to 1/5 of a second.

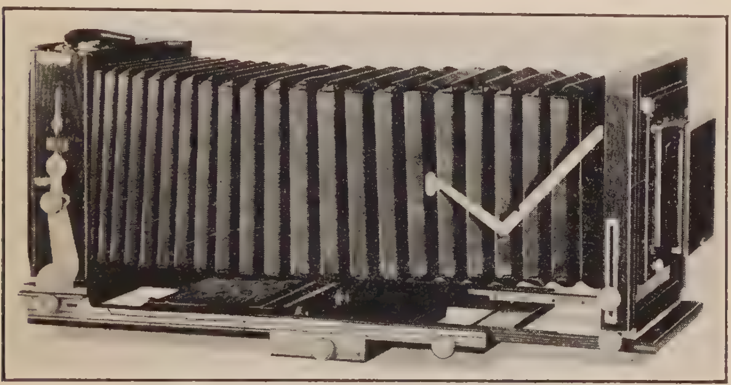


FIG. 18. Professional View Camera

The reflex camera offers several distinct advantages possessed by no other camera, which renders it well worth its cost, which is necessarily rather high owing to the care needed in manufacturing and properly adjusting the intricate mechanism. The image can be seen in full size, right side up on the focussing screen until just before the exposure is made. Thus the reflex is superior to the folding film camera in that it is possible to focus accurately on the ground-glass and not have to depend upon focussing scales. It is superior to the ground-glass focussing plate camera in that the image is right side up so that composition and placement of the subject is simpler and also in the fact that the exposure can be made immediately without the operations of closing the lens, inserting the plate-holder, withdrawing the slide, etc. Furthermore, very rapid exposures are possible since the ordinary focal plane shutter works up to a maximum speed of 1/1000 second.

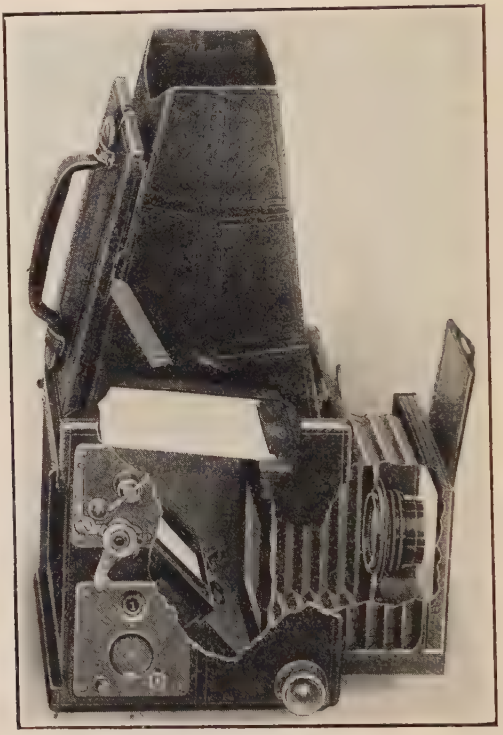


FIG. 19. Principle of the Reflex Camera

Aside from its expense, the principal objection to the reflex is its bulk and weight. There is no doubt that where portability is an important factor the average reflex is rather out of question. The 3¼ x 4¼ instrument weighs from four to five pounds and occupies a space of approximately 5 x 5 x 6 inches, while the 4 x 5 size is correspondingly larger. The first mentioned size is the more popular of the two. For those who demand portability and yet desire reflex advantages the 2½ x 3½ size may be recommended, while the 5 x 7 size is practically obsolete except among professional workers.

To overcome the bulk of the box form reflex many manufacturers, especially in foreign countries, have placed folding models on the market. These are much more costly, and are neither as substantial in construction nor do they possess the usual bellow extension, extent of rising and falling front, etc., so that at present the box form type is, perhaps, still the best. While especially suitable for photographing objects in rapid motion, the reflex is by no means limited to work of this class. Indeed for all ordinary work it is the most certain and convenient instrument to use. It is of course not suited to architectural work when a swing-back is required and in most cases cannot be well used for copying, but for all general work in the field or at home the reflex is ideally adapted.

The Principal Adjustments of Cameras.—The principal adjustments of cameras are the rising and falling front, the vertical swing or swing-back as it is commonly termed, the horizontal or side swing, and the reversible back.

The rising and falling front is an arrangement for raising or lowering the position of the lens in order to increase or decrease the amount of foreground included. While at times necessary in all kinds of work, it is particularly valuable in architectural work where it is necessary to include the whole of a tall building. The amount which the lens may be raised is usually expressed as a fraction of the greatest length of the plate. Thus if the rising front on a 4 x 5 camera allows the lens to be raised one inch above its normal central position the degree of rise is said to be 1/5. The amount which the lens can be raised varies in different makes of cameras but is always greater in view cameras than in the more compact hand and stand cameras.

Wide limits of rising front are sometimes required in exacting cases and at any rate it is well to secure a camera allowing the maximum rise and fall for a camera in its class as the reserve rise will at times help one out of difficulty. To secure the full advantages of a camera having extreme rise, a well-corrected lens with a reserve covering power is required, since when the lens is raised above its normal position it is the margins of the field rather than the center that are used and consequently the greater the demand for good correction, since the definition of a lens is never so good near the margins as at the center. Reserve covering power is needed in order that the plate may be completely covered when the lens is fully raised.

While many film cameras are provided with a rising and falling front its utility is in this case somewhat doubtful, since the finder cannot be relied upon to show just what is included when the lens is not in its normal position. Several makes of cameras, however, are fitted with self-adjusting finders which more or less accurately indicate the exact limits of the picture when the lens is raised above its normal position.

The Swing-Back.—The swing-back is an adjustment for swinging the back of the camera at an angle to the bed so that the plate may be kept in a vertical position, when the camera is pointed upwards in order to include a lofty subject on the plate. In *a* of Fig. 20 the camera is supposed to be absolutely level so that the parallel lines of the subject *A* and *B* are represented by parallel lines *A′* and *B′* in the image formed by the lens *L*. In this case there is no distortion. However, when the camera is tilted upwards as in *b* of Fig. 20 the

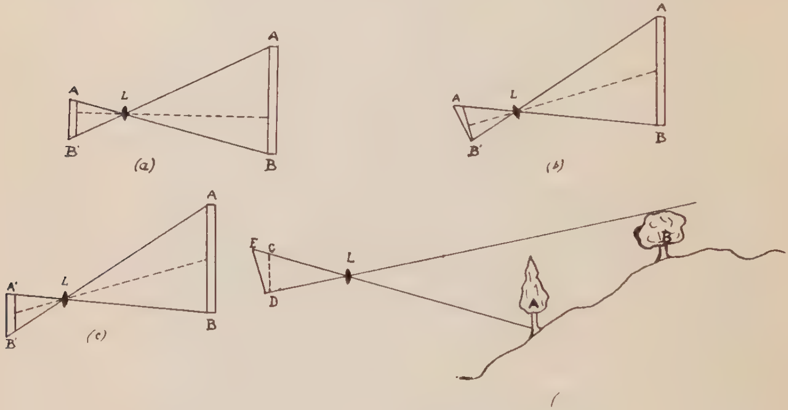


Fig. 20. Principle of the Swing Back
Use of the swing back for securing greater depth of focus

sensitive plate is no longer parallel with the subject *AB* and consequently the parallel lines *A* and *B* of the subject are represented as converging lines in the image. However, if the camera is fitted with a swing-back, the plate can be brought to a vertical position by properly adjusting the back and distortion will be avoided although the bed of the camera be tilted upwards. However, as will be observed from *c* of Fig. 20, the axis of the lens is no longer at right angles to the sensitive plate, but crosses it obliquely, so that the use of a small diaphragm is necessary to obtain sharp focus over the entire area. The size of the diaphragm required depends upon circumstances and can only be determined by examination of the ground-glass image.

The other use of the swing-back is in focussing different planes at varying distances from the camera sharply, without using small diaphragms. Suppose we are required to photograph the side of a hill on which *A* and *B* represent objects of interest which it is necessary to focus sharply without the use of small diaphragms. With the plate in the horizontal position *CD* it is evident that the distance *BD* is greater than *AC* and that only one of these objects can be sharply focussed unless a small diaphragm is used. However, if the swing-back is adjusted so that the sensitive plate occupies the position *DE,* the distance of the plate from *A* is increased while BD remains the same. By watching the focussing screen while making these adjustments it is easy to bring about some compromise which will allow a larger stop to be used than would otherwise be possible. In every case in which the axis of the lens is not at right angles to the plate a certain amount of distortion results, so that this movement cannot be used for certain kinds of work, but on landscapes, portraits, etc., the small amount of distortion may pass unnoticed. Indeed in some cases it is a positive advantage since it emphasizes the nearer objects. At any rate the worker must determine for each particular case, by examination of the image on the ground-glass, whether the distortion is objectional or not.

Swing Front.—The swing front is an adjustment which is very useful at times and which unfortunately is included on very few cameras, even those built exclusively for professional use. When the front is hinged at the base, as in some reflex and stand cameras, the chief function of the swing lens is to provide an increased amount of rising front when employed with the swing back. When the camera is tilted upward and the back adjusted vertically so as to preserve the parallelism of upright lines in the picture, the shift in the image is proportional to the tilt given the camera, but if the camera is provided with a swing front, the lens may be made parallel to the back thus we include still more of the sky and less of the foreground so that we secure, in effect, an extreme rise of front which is frequently very necessary, as in photographing a modern skyscraper. Furthermore, the lens is parallel to the plate, so that less stopping down will be required for sharp definition.

Even of greater service is a swing front which swings from the lens rather than the base of the camera front. A swing of this description, when used in conjunction with the rising front, may effectively take the place of the swing back. If, when the lens is thus raised extremely high, the lower corners of the plate are badly illuminated or cut off, the lens can be tilted slightly upward and the illumination on the plate will be restored without material shift of the image. Another advantage in the use of the swing front is that by pointing the lens slightly upward or downward it is possible to obtain increased depth of focus without the distortion which is produced when the swing back is used for the same purpose. In this way objects near the camera can be brought into sharp focus at the same time that the distance is sharp and with a comparatively large stop. The use of the swing lens in this manner, however, presupposes the use of a lens which has a sharp field larger than the plate.

The Reversible Back.—The reversible back allows the back of the camera to be reversed so that the picture can be made either horizontally or vertically without turning the camera on its side. This is a very convenient feature and is found on all of the more expensive plate cameras except those which must be made extremely compact. It cannot be had on any roll film camera, all of which must be reversed when a horizontal picture is required. Some cameras are fitted with what is termed revolving backs instead of reversible backs. These serve the same purpose but, as their name indicates, they are revolved from one position to the other without being detached from the camera.

Other Movements.—Some cameras are also fitted with side swings which allow the plate to be adjusted with reference to horizontal objects. While at times valuable, the horizontal or side swing is not nearly so important as the vertical swing or swing-back, and for that reason it too is found only on the professional view camera and the more expensive hand and stand cameras.

The sliding front is an adjustment fitted to only a few cameras and these are generally view cameras for professional use. When two pictures are made on the same plate, the lens may be moved to each side in order that the center of the field may be used.

There are many other adjustments fitted to various makes of cameras which are not sufficiently universal in application to require attention.

Shutters.—Photographic shutters may be conveniently divided into four classes according to whether they are placed before, between or behind the lens or in the position of the focal plane. Of the first class little need now be said for shutters of this class have almost completely disappeared. The few types of behind-the-lens shutters remaining are used almost wholly for studio portraiture. This leaves us then the two classes of shutters in general use, namely, the between-the-lens, or diaphragm shutter as it is sometimes termed from its close proximity to the diaphragm, and the focal plane shutter.

The between-the-lens shutter consists of from three to five blades of thin steel or hard rubber, which open and close from the center, the time during which the leaves are open being controlled either by an air-brake or a chain of gears. Most of the later shutters, such as the Ilex, the Wollensak, and the Compur, to mention only a few well-known makes, belong to the last named class. The shutters controlled by a chain of gears are generally more accurate in their timing than those controlled by pneumatic means although this is not always the case. The accuracy of timing in most shutters, even of the best types, leaves much to be desired.

The speeds marked on most shutters are only approximate and the actual speeds not infrequently show considerable departure from the marked values. The difference between marked speed and actual speed is generally most evident in the shorter exposures. The exposure marked 1/250 is seldom more than 1/200 and frequently much less. The lower speeds, on the whole, show less deviation, although it is not altogether uncommon to find a shutter which shows but little variation in actual speed between the indicated speeds of 1/25 and 1/100 of a second. Shutters, the speeds of which are approximately correct when new show considerable variation after a season or two, although the modern gear-controlled shutters are less likely to "go off" than the others.

The focal plane shutter is thus termed because it operates close to the focal plane and immediately in front of the sensitive material. It consists of a light-tight curtain pierced with slits of various width. This curtain is carried on two rollers, one of which is under tension. When the exposure lever is released, the curtain rolls off of one roller on to the other, making the exposure as the open slit passes in front of the plate or film. A wide range of exposures may be had by varying the size of the slit in the curtain and by increasing or decreasing the tension, which controls the speed at which the slit is drawn past the plate or film.

With a focal plane shutter the actual speed values correspond more closely to the marked values than with the between-the-lens shutter, except when old and the tension weakened. The efficiency of the focal plane shutter is higher than that of the between-the-lens shutter, efficiency being taken as the actual amount of light which reaches the plate in a given time of exposure. No matter what the exposure, the leaves of a diaphragm shutter take some time to open and close. Thus the lens is working at full aperture for only a portion of the exposure. With the focal plane shutter, however (provided the shutter is placed close to the surface of the sensitive material), the full aperture of the lens is utilized, so that considerably more light reaches the plate or film in a given exposure time than with a between-the-lens shutter. The efficiency of the best diaphragm shutters varies between 50–60 per cent; that of the best focal plane shutters between 80–90 per cent, so that there is a distinct advantage in the use of focal plane shutters at the higher speeds.

Tripods.—Metal tripods have largely replaced the wooden variety except for use with the larger professional cameras. A great many of the light and compact metal tripods are lacking in stability and are suitable only for the lightest cameras. Nothing is more annoying than a wobbly tripod and except where weight and size are the determining factors, the lighter metal tripods should be avoided. While a trifle less compact, those tripods in which the members are hinged so that the legs open up in the manner of a folder have greater strength and are more easily erected, as the sliding type with time tends to give trouble from bending.

Few metal tripods have a head which allows the camera to be tilted except by unequally spreading the legs. Tilting and revolving tripod heads, however, may be bought quite reasonably and are almost indispensable. Special stands have been introduced for home portrait and general interior work by a number of firms. The leg braces and central elevating post of these make their use preferable to the usual form of tripod for interiors or wherever there is danger of slipping.

Lens-Hoods.—Lens-hoods are necessary when the lens is pointed towards the source of light and advisable at all times, especially with compactly mounted, large-aperture, anastigmat lenses. These, unlike the older lenses, generally have no projecting hood, while their short barrel length, large aperture and more complex construction all favor the formation of internal reflections which reduce the brilliancy of the image. The general disregard of lens-hoods is simply another instance in which the craze for compactness and simplicity has got the best of what is the better practice so far as optical performance is concerned. So little is the value of the lens-hood appreciated at the present time that it is almost impossible to find a really efficient lens-hood for a small camera. Any black lined tube, however, which projects as far as possible in front of the lens without cutting into the picture, serves the purpose, whatever it may lack in convenience.

Finders.—Finders are of two general types: (1) reflecting and (2) direct. The reflecting type is that usually fitted to hand cameras and consists essentially of a small camera obscura with a slip of mirror at an angle of 45 degrees to the lens, so as to reflect the image to the top. Most of the finders fitted to hand cameras are too small to be used to the best advantage. Furthermore, they do not show the image as it will be recorded by the lens. The customary finder shows only approximately what will be included in the picture. The separation between lens and finder is not important for distant objects but is for very close objects, say within 5 to 6 feet. Consequently, a finder which indicates correctly the field included with a distant object may fail to do so with a close one. When the lens is raised or lowered the image in the finder is not altered proportionately. This limits the use of the rising front on roll film cameras. The "Sybil" finder of Messrs. Newman and Guardia, however, provides for this by a set of number marks and the "Idento" finder of Messrs. Adams has an automatic masking arrangement which insures correspondence when lens is raised or lowered.

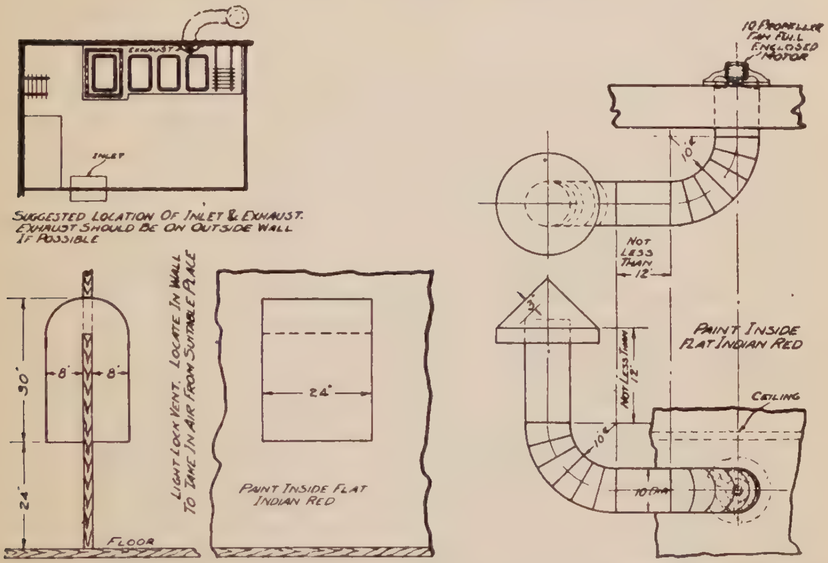
The direct finder may be a rectangular lens on which the image is viewed from a sight rod, or it may be simply a wire frame the dimensions of the picture area, attached to the lens or shutter mount having a sighting rod on the side of the camera. Either form is preferable to the reflecting finder: (1) it allows the use of the camera at eye-level, which is usually preferable to waist-level, (2) it is much easier to follow moving objects and (3) the size of the image is larger. Direct finders may also be made to compensate for the raising or lowering of the lens although in most cameras this is not done.

II. The Darkroom

The Size of the Darkroom.—The important part played by the darkroom in the quality and volume of the work produced is not as fully realized as it should be. As a consequence, we have many darkrooms which are mere makeshifts, which are ill arranged and result in serious loss of valuable time and materials, and in some cases injurious to the health of the photographer and to the sensitive materials he uses. It is well worth while to pay particular attention to making the darkroom an orderly, well-arranged place, which is both healthful and pleasing, a place which one will not object to living in.

The size of the darkroom is in most cases determined by the circumstances attending to its location. The proper size is determined by the character as well as the volume of work carried on. For the average amateur there is no particular advantage in a room larger than ten by twelve feet, while about six by six feet may be regarded as the minimum. The advantages of a workroom about eight by ten or ten by twelve feet are: the greater ease in heating and ventilating, and less danger from stray light from openings in the walls or from around the door or window. A room with these dimensions allows an enlarging lantern to be installed and provides room for separate benches and sinks for different operations, as plate changing, plate developing, printing, washing, etc.

For commercial work no definite size can be stated, as this will depend upon the class of work and upon the volume of business. In any case, room should be provided to allow sufficient space for each operation so that there may be a separate and distinct place for each operation and for the materials and equipment required for this particular operation. When this is done things are not so often misplaced, broken, overlooked or destroyed. For a large business it is an advantage to divide the workroom into several smaller workrooms each of which is equipped and used for one particular purpose and no other. Thus we may have one moderate-sized room for plate changing and development, another for printing, and still another for the storage of chemicals and for preparing solutions. Of these three rooms in most cases the printing room requires to be the largest, and the room for developing next in size, while the chemical storage room may be comparatively small since it is not in constant use. If only a small amount of enlarging is done the apparatus may be installed in the printing room, but if enlarging forms an important part of the business it is well to provide a separate place for this purpose.


EXHAUST
INLET
SUGGESTED LOCATION OF INLET & EXHAUST. EXHAUST SHOULD BE ON OUTSIDE WALL IF POSSIBLE
30"
24"
8"
8"
FLOOR
LIGHT LOCK VENT. LOCATE IN WALL TO TAKE IN AIR FROM SUITABLE PLACE
24"
PAINT INSIDE FLAT INDIAN RED
10 PROPELLER FAN FULL ENCLOSED MOTOR
10"
NOT LESS THAN 12"
3"
NOT LESS THAN 12"
PAINT INSIDE FLAT INDIAN RED
CEILING
10"
10 DIA

(*Courtesy of Eastman Kodak Company*)

FIG. 21. Ventilation of the Darkroom

Ventilation.—A matter of particular importance, to which little or no attention is generally paid, is proper ventilation. In the opinion of the writer it is undesirable to have as a darkroom one which is permanently dark. If conditions will permit, it is far better to have a room which includes at least one window, or more if the room is large, which is provided with a tight-fitting, light-proof blind which may be quickly opened to admit air and light and as quickly closed for work. While this will be of considerable service in ventilating the darkroom, and may be sufficient for the amateur who only works for a short period of time, something more is required in large establishments where the room is used throughout the day. Here it is necessary to provide light-proof air vents in order to allow the entry of fresh air and if the exit vents are fitted with suction fans so much the better. We illustrate in Fig. 21 a plan for the ventilation of the workroom which will be found quite satisfactory. A ten-inch propeller fan will handle about 300 cubic feet of air per minute and is large enough for a room containing about 4000 cubic feet of air. While this may seem elaborate and unnecessary expense, it can be proved that the gain in general efficiency more than compensates for the initial cost while the good will of the employee cannot be estimated in dollars and cents.

Arrangement.—The arrangement of the darkroom is a matter deserving particular attention. In laying out the floor space the aim should be to allow plenty of space to enable an operation to be carried on quickly and efficiently without hindrance to other work which may be going on at the same time. To do this there should be a separate place for the materials and apparatus for each operation and this should be convenient to the place where the work is carried on so that articles required may be readily accessible. Forethought along these lines and careful planning of the workroom with a view to the requirements will save much time and labor later.

Two very suitable arrangements for the amateur are shown in Fig. 22, one for a room and the other for a closet which is to be converted into a workroom. It will be observed that in both cases the space for loading plates and developing is placed behind the door where there is less danger from stray light. The space for loading plate holders or development is marked *A* in both floor plans, while *B* represents the sink in which the fixing bath and washing tanks are kept. The enlarging lantern may be conveniently placed in either at *C* and a separate bench for the printing machine and cabinets for papers and plates may be placed along one of the free sides of the room.

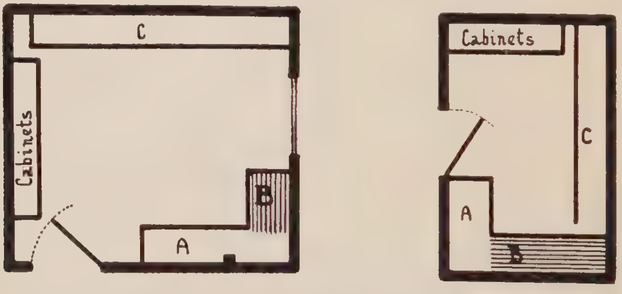


FIG. 22. Floor Plan of Darkroom for Amateur Use

The Water Supply (Sinks).—As a large amount of water is required for most photographic operations, the water supply is an important item in the location of the darkroom, which should be located, if possible, so that water may be easily installed. For while running water is not an essential, at least for the amateur who works at intervals, though it may be regarded as an absolute necessity for the professional, it is a decided convenience and adds much to the pleasure of the work. Owing to the location of the darkroom it may be impossible to install running water either because the mains are not available or the cost is prohibitive. In such cases the amateur will find a very good substitute in a large water cooler of about five gallon capacity. This should be fitted over the sink in such a position that the tap is conveniently located for the drawing of water for the dilution of solutions and rinsing of plates after development. A similar container may be placed below the sink. Operations which require a large amount of water, as the washing of plates or prints, will then be carried out in another room where running water is available.

Opinions vary regarding the proper size and the construction of the sink. In the opinion of the writer it is a mistake to have a sink smaller than 18 by 36 inches. A sink of this size is just sufficient to carry a cold and a hot water tap together with the negative fixing tank, which should always be kept in the sink in order that there may be no danger from hypo infection. Larger sinks offer advantages in that they may contain in addition the negative washing box and the print washer or other similar apparatus. On the other hand they quite frequently occupy valuable room and are otherwise objectionable because they keep the room damp and unpleasant and cause metal goods, as the enlarging lantern, to rust. In arranging for the sink the worker must be guided by his own requirements and by the space available. The sink itself may be of wood coated with a waterproof paint, such as Probus; of cement, of enameled steel, or of lead. Steel enameled sinks are perhaps the most satisfactory and are really the cheapest in small sizes but are obtainable only on special order in very large sizes and are also very expensive. Large sinks are therefore generally made of either cement or wood coated with a waterproof paint. Taking into consideration the labor involved in constructing the same, the wood sink is the cheaper and is perfectly satisfactory, provided it is kept well coated with a water-, acid- and alkali-proof paint. In the laboratories of the Division of Photography at The Pennsylvania State College, the writer for several years had two wooden sinks, covered with an alkali- and acid-proof paint, in almost constant use and they have proved perfectly satisfactory. The only precaution to be taken is to renew the coating of paint once or twice a year. The majority of sinks, however, are made of concrete, which is resistant to all acids and alkalies of such strength as are used in ordinary photographic practice. The following directions for the manufacture of a large concrete sink were given at a meeting of the Photographers' Association of America some twelve or thirteen years ago. A framework of half-inch boards is first built on the support where the sink is to be placed, and on this a thick layer of cement and sand in the proportion of cement two parts and sand three parts is laid, about an inch thick. While this is setting, an inner framework of half-inch boards, about two inches shorter than the outer one and without any bottom, is prepared and when the bottom layer of cement is set, this inner framework is rested upon it, and the tops of the inner and outer framework are kept steady at a distance of about an inch apart by two strips of wood attached at distances at the top. This forms a mould between the two frameworks and the bottom layer of cement, and into this mould more cement mixture is poured and allowed to set. The waste pipes should be put in before the cement sets and placed a little below the surface to allow for the shrinkage which occurs upon drying. To strengthen the sink large nails, or pieces of iron or steel, may be imbedded in the cement and if thoroughly covered they will not rust. When the cement has become thoroughly hard the forms may be removed and work begun immediately. If the somewhat rough surface is objected to for any reason the cement may be coated with any of the compounds used for finishing cement surfaces and will then be perfectly smooth and resistant.

In fitting taps over the sink care should be taken that they are not so low that large graduates or containers cannot be placed under them. Placing the taps too high is also to be avoided owing to the trouble from splashing. A height of about fifteen inches from the bottom of the sink is a fair distance.

The Illumination of the Darkroom.—There are two systems of darkroom illumination, direct and indirect. Indirect light, while having been adopted by some large commercial houses, has been neglected by the amateur and even by the average professional. The advantages of indirect light are many, as will soon be observed by one who installs it, and the amount of light which may be present in the darkroom without danger of fog on even the most sensitive of modern plates, when handled with reasonable precautions, will astonish one. As a matter of fact most darkrooms are too dark and in the end not so safe as supposed, since it is necessary to work quite close to the light—not one of which is really safe. An overhead light will give an even, diffused light all over the room and there is no difficulty in finding articles which may be required.

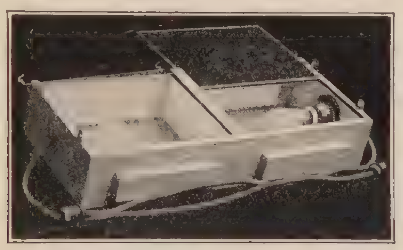


Fig. 23. Eastman Indirect Darkroom Lamp

Lamps for indirect lighting are supplied by the Eastman Kodak Company (Fig. 23) but there is nothing to prevent the worker from making his own if he so desires, as the construction is quite simple. The light-box itself (see Fig. 24) is made of thin sheet iron and is 8 x 10 x 6½ inches in size. There are two ventilators, one in one side

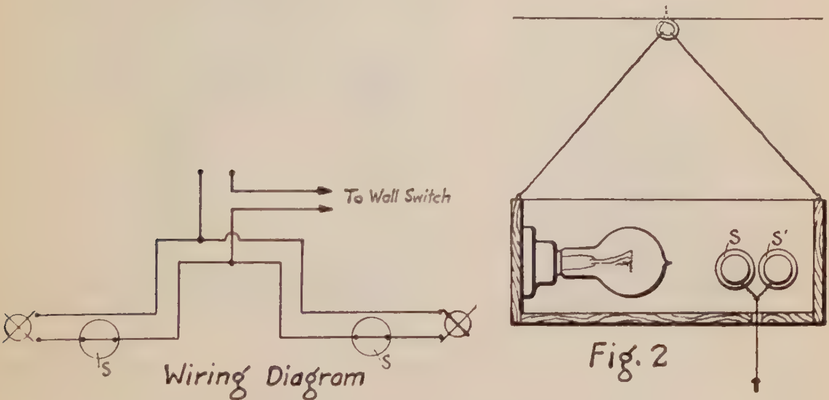


Fig. 24. Design for Indirect Darkroom Lamp.
(Krug, *American Annual of Photography*, 1922)

and one in the bottom of the box, which must be made so as to prevent any white light from passing. The interior of the box is painted with a matte white or aluminum paint and the electric socket is placed so as to bring the filaments of the bulb nearly in the center of the box. The top is hinged so as to permit of changing the safelight to suit emulsions of different character. The box is suspended from the ceiling by four chains or wires attached to each corner and the electric light cable is brought down from the wall tap which should be close by. To secure the full advantage of the light the ceiling should be a white matte; however, if this is not the case a sheet of Beaver board about four feet square and painted white may be fixed to the wall directly above the light. Under these conditions the illumination will cover an area about sixteen feet square so that additional light will be needed for a large room. A 25- or 40-watt bulb will supply sufficient light; very large bulbs will melt gelatine safelight screens. The safelights used will, of course, be those which are adapted for the type of sensitive material in use. This matter we will consider shortly.

A very convenient lamp for the development of prints or enlargements or for either time or factorial development, where there is no occasion for examining the negative by transmitted light, is the pendant light (Fig. 25). As the safelights are interchangeable the same light may be used for developing either plates or prints, the safelights being changed as the occasion demands.

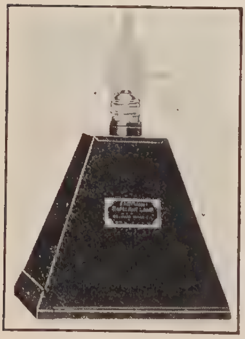


Fig. 25. Eastman Developing Lamp

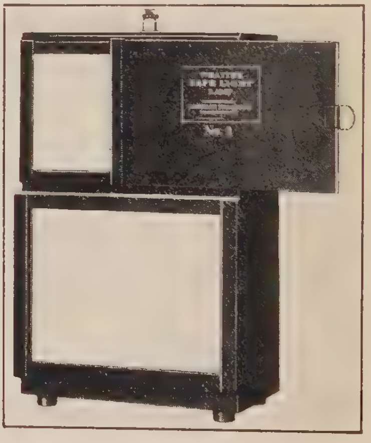


Fig. 26. Wratten Darkroom Safelight Lamp

Among the many excellent types of lamps on the market for direct illumination the Wratten (Fig. 26) may be mentioned for the facility with which the safelights may be changed, for perfect ventilation, and for the uniform and safe illumination by using only reflected light.

All the lamps which we have mentioned are for electric light only and certainly no one who has access to electric current will use anything else. Where gas or oil must be used the best plan is to place the light outside of the darkroom itself and arrange a holder for the safelight in the wall of the room. Where this cannot be done it is necessary to purchase one of the gas or oil lamps obtainable from dealers. In purchasing examine first the size of the lamp (5 by 7 inches should be regarded as the minimum size for the safelight); second the arrangement for changing safelights for different plates; and third see that the ventilation is well taken care of. Most commercial oil lamps are deficient on all of these points but more particularly the second and third. Do not make the mistake of buying a cheap lamp, but examine carefully the various models and do not hesitate to pay a fair price for a well-built and efficient lamp which will fulfill your requirements.

The Safelight.—The term safelight is in a sense a misnomer as there is really no such thing as a "safe" light, for any light that is bright enough for the eye to observe will affect a plate if it is exposed to it sufficiently long. It is entirely a matter of time. It is well to remember that, regardless of the screen used for development, the plate should be exposed to the light as little as possible, only at the beginning of development to see if the plate is evenly covered and then towards the end of development to determine when the plate should be removed, and the tray should be kept covered at all other times. Under these conditions it is possible to use a fairly bright light for development with comparative freedom from fog.

In the earlier days of photography when plates were not nearly so rapid or as color sensitive as they are at the present time, the common materials used were ruby glass and canary fabric. While both of these materials pass a considerable amount of active light, they were satisfactory with the plates then in use and indeed are still widely used, but with the advent of the modern highly color-sensitive plate the ruby glass screen is giving way to the modern safelight, composed of certain dyes, which are selected so that the combined transmission is that to which the plate for which it is designed is least sensitive. These screens are made by several manufacturers, in different series, for plates of different color sensitiveness, or they may be made at home, but as there are many excellent screens at very reasonable prices on the market it is a mistake and false economy to make one's own.

The Efficiency of Darkroom Safelights.—With any darkroom screen we naturally wish to secure the maximum safety with the greatest visual intensity, or in other words the brightest light that is safe for the plate. Thus, if a plate is sensitive only to the ultra-violet, violet, and blue, and is insensitive to green and red, either a green or a red safelight might be used with safety. The most efficient of the two screens, and therefore the best choice for practical work, would depend upon the relation between the sensitiveness of the plate and the sensitiveness of the eye for any particular color. The visual intensity is higher for the green than the red, but the latter has less action on the plate, so that with ordinary plates where a fair volume of light may be used, the red screen is used in preference to the green, but in the special case of the panchromatic plate, which is sensitive to practically the entire visible spectrum, so that only a very small volume of light may be used, the green is chosen because of its greater visual intensity.

The standard of safety adopted for the products of at least one manufacturer of screens is that no effect should be produced on the plate when it is exposed to the safelight at a distance of one meter for thirty seconds. Most screens will produce fog if rapid or highly color-sensitive plates are exposed to their action for much over a half minute. A good working test of safety is to place a plate facing the safelight and about two feet away and expose part of it for thirty seconds, leaving part of the plate unexposed by covering it with several coins, or a piece of black paper. If the plate shows signs of fog, after development in *total darkness* for the usual time, the light is unsafe for the plate and either a weaker light source should be used, the plate handled at a greater distance from the lamp, or the safelight should be changed to one which more nearly transmits light to which the plate is insensitive.

Before leaving the subject of safelights we would again caution the worker about exposing plates to the safelight more than is absolutely necessary. This is particularly important when loading holders and before the plate is placed in the developing solution, as the sensitiveness decreases as development proceeds, so that a light which may be safe for examining the plate when partly developed may be relatively unsafe for the same plate in the dry state. It is not a difficult matter to learn to load plates in the dark and it is far more satisfactory to do so. With time development there is no necessity for observing the plate at all unless greater or less contrast than the normal is desired, and then it is not necessary to examine the plate until development is nearly complete. The same applies to development by inspection. Particular care must be taken when the factorial method of development is used, since in this case the plate must be held rather close to the light at the beginning of development in order to observe the time of appearance of the image. This difficulty may be overcome by the use of a desensitizer.

Trays, Tanks and Graduates.—Trays having the same dimensions as the plate used are really convenient only for special operations such as reducing, intensifying, etc., and it is far better to purchase developing trays which will accommodate at least four plates at a time. There is very little to choose between hard-rubber, porcelain, or steel enamel trays. All withstand all ordinary photographic solutions. While the first are expensive and easily broken, the second are rather expensive and also somewhat clumsy on account of their weight, and the last has the disadvantage that the enamel becomes chipped in time and exposes the metal to the action of the solutions. Composition trays are as satisfactory as any and if broken can be replaced with less outlay than any of the others.

Now that tank development is so largely employed by both the amateur and the professional it may be well to say a word regarding the tanks for the development of plates and also those adapted to the use of roll film. Practically all of the tanks on the American market which are designed for the use of plates are made of nickeled steel and fitted with a waterproof cover so that the tank may be turned over on its end in order to agitate the developer and prevent uneven density. In several of the tanks on the market provision is made for pouring in the developer through a light-proof trap after the plates have been loaded into the tank. Then, when development is complete, the developer may be poured out through the same tap and replaced by pure water for rinsing and finally by the fixing bath. Thus all operations except the loading of the tank with plates may be done in full daylight, while it is quite an easy matter to load the tank with plates without a darkroom by using a changing bag. Other tanks have very ingenious loading devices which enable the tank to be loaded quickly without the danger of touching the sensitive surface or exposing the plate to the light very long. The Kodak film tank is an example of the all-by-daylight method of developing roll film whose use is too well known to require more than a brief mention.

Only three sizes of graduates are required for all ordinary purposes, although others may be useful at times. The sizes most generally required are a one-ounce minim graduate, one of about 8 ounce capacity and a larger one of 16 or 32 ounce capacity. For the larger sizes the cheap tumbler graduates having pressed instead of engraved lines are sufficiently accurate. By paying somewhat more one can secure graduates having opaque graduations which can readily be seen in the darkroom, so that there is no uncertainty in preparing solutions while developing. Two special forms of graduates also require attention, viz.: the graduated beakers used by chemists which are practically unbreakable, and the combined graduate and mortar and pestle which is extremely useful for powdering chemicals or crushing tablet developers, as the Tabloid or Scaloid products.

It is essential that all trays, tanks, and graduates be kept thoroughly clean. Many of the stains and other defects which perplex the amateur and trouble the professional at times are due to unclean trays or other similar equipment. One of the most effective means of rapidly removing any ordinary chemical impurity from a vessel is by the use of a solution of potassium bichromate and sulphuric acid. The proportions are not so very important and the following will be found about right:

Water to make	32 ounces	(1,000 c.c.)
Potassium bichromate	4 ounces	(125 gms.)
Sulphuric acid (commercial)	4 ounces	(125 c.c.)

This is poured into the vessel and will act in a minute or so, when after a rinse or two and some swabbing with a tuft of absorbent cotton the tray or graduate will be chemically clean and available for any photographic operation. The solution should be kept in a glass-stoppered bottle, as it will destroy a cork.

Commercial Tanks.—In commercial establishments where a larger volume of work is done, the use of open tanks is general. The sensitive material, whether plates, cut film or roll film is carried on suitable hangers through the operations of developing, fixing and washing. The tanks for use with plates and cut films hold from 1 to 3½ gallons of developer and accommodate from 1 to 2 dozen plates or cut film at a time. The larger tanks used for the development of roll film hold from 10–50 gallons of developer and take from 10–50 rolls at a time. With such installations, it is not the usual practice to discard the developer after each batch of plates or film but to keep the solution up to normal strength by the addition of fresh solution.

Lately, there have been introduced for the development of roll film automatic developing machines which carry the loaded film hangers through the developing, rinsing, fixing and washing tanks without attention on the part of the operator. These machines are capable of developing up to 500 rolls of film per hour and require the services of but two men; one to attach the rolls of film to the conveyor and one to remove the films in the drying room. They have proven entirely successful and are used in a number of the larger photo finishing plants.

Some Miscellaneous Workroom Features.—It is always advisable to keep the major part of the stock of sensitive materials on hand outside the workroom but provision ought to be made to keep those which are constantly in use where needed in the workrooms and in such quantities as may be required. To this end it is well to construct tight wooden cabinets to contain all plates, films and papers in general use not only in order that such materials may be kept in an orderly condition but to prevent injury by the moisture always present in the workroom. Such cabinets may also be provided for containing loaded and unloaded plate holders and for the weighing and mixing of chemicals.

The drying of plates and films is a matter of some moment, especially in large commercial establishments where it is necessary to dry batches of plates or films at a uniform rate day in and day out regardless of the weather conditions outside. We illustrate in Fig. 27 a small cabinet designed for plates or cut film and intended more particularly for the serious amateur or small professional. For a larger establishment and where provision must be made for drying roll film more elaborate equipment is necessary. The size of the cabinet will be governed largely by the number of films handled in a batch and the number per day. It should be sufficiently large, however, to contain all the films it is likely to be called upon to handle at one time without undue crowding and ample space should be allowed for the circulation of air on all four sides and through the center. Either sliding or swing doors may be provided, while if desired one may place doors on two opposite sides, the films direct from the washing tank being inserted from one side and removed from the other after drying. To secure a thorough and even circulation of air it is advisable to provide both the bottom and top of the cabinet with an air cabinet. Both the upper and lower walls of the bottom air cabinet should be made perforated, using ½ inch holes spaced two inches apart each way. The holes of the two walls should not coincide, however, or

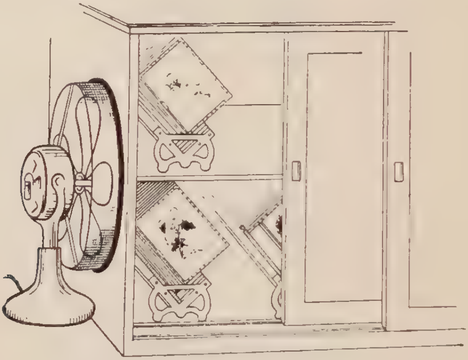


FIG. 27. Drying Cabinet for Plates and Films

the purpose of the air chamber will be defeated. The bottom of the upper air chamber should also be perforated and provision made at the top for the installation of a suction fan to create a current of air through the cabinet. Provision for suspending the films will naturally depend upon the type of hangers employed and can be worked out by the individual to meet his own particular case. Heat may be used for drying if a thorough even circulation of air is assured but not otherwise. The best results are obtained at 95 degrees Fahr. and a thermometer should be kept within the cabinet and in plain view to see that this temperature is not exceeded.

Drying cabinets for roll film are an article of commerce and may be obtained from a number of dealers should the worker prefer not to build his own.

Such cabinets may also be used for drying prints on squeegee plates. Commercial apparatus for this purpose is also available.

CHAPTER III

PHOTOGRAPHIC OPTICS

Introduction.—According to the theory now generally accepted, light is a wave motion in an elastic medium known as ether. The vibratory motion of the molecules of a body are communicated to the ether and a transverse wave spreads out in all directions with a velocity of approximately 300,000,000 meters per second. When this wave motion strikes the eye it produces the sensation which we term light.

We distinguish between *luminous* and *illuminated* bodies: the former radiate light of themselves, the latter are simply bodies on which the rays from a luminous source fall. Among the former are included the sun, all artificial lights as oil, gas, electric and magnesium, and every body heated above a certain point. Illuminated objects comprise all bodies in the unobstructed path of rays from a luminous source. The intensity of illumination on an illuminated body depends upon the strength of light at the source, the distance of the illuminated body from the light source and the density of the intervening medium.

While light waves spread out in all directions from the source, the vibrations which reach any point travel a straight line joining that point and the source. This is known as the *rectilinear propagation of light.*

A cone of rays from a luminous point is known as a *light*-pencil, and is said to be *homocentric* to all other pencils which proceed from the same luminous point. The central line of this light-pencil is termed the *axis.* If we follow the rays from the source they are said to be *divergent;* in the opposite direction, *convergent.*

Refraction of Light.—In a homogeneous medium the path of a ray of light is always straight, but the passage of the ray from one medium to another, in general, alters both its velocity and its direction. The alteration in the direction of a ray upon passing from one medium to another is known as *refraction.* The angle which the incident ray makes with the normal to the surface at the point of separation of the two mediums is known as the angle of incidence, while the angle of the refracted ray to the normal is known as the *angle of refraction.*

A ray (see Fig. 28) *A* moving in a medium 1 meets at *B* the surface

CD separating the medium 1 from a denser medium 2. Upon striking the surface *CD*, the ray is divided into two rays *BE* and *BF*, the former the reflected and the latter the refracted ray. The angle of the reflected ray is equal to the angle of the incident ray, so that the angle of incidence equals the angle of reflection. When the ray passes from one medium to another of greater density, as from air to glass, the refracted ray *BF* is bent *towards* the normal, but when passing from a dense medium to one of lesser density the path of the refracted ray lies *away* from the normal.

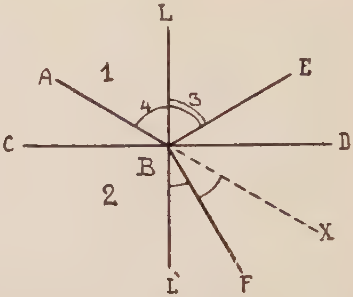


FIG. 28. The Principles of Refraction

The angle of deviation of a ray upon passing from one medium to another is known as the *index of refraction*. Since refraction is due to a change in the velocity of light the refractive index of a medium is equal to

$$\frac{\text{the velocity of light in air or a vacuum}}{\text{the velocity of light in the given medium}}$$

The amount which the refracted ray deviates from the direction of the incident ray, or the index of refraction, can be determined from the size of the angles *ABL* and *BFL'*. Thus the angle $BF = ABL - BFL'$. Or, where i is the angle of incidence, r the angle of refraction and D the deviation, the value of D is obtained by the following equation:

$$D = (i - r).$$

Thus far we have only considered refraction at one surface. When we have a plate of a dense medium, as glass, a ray of light is refracted both upon entrance and also upon emergence. Let *ABCD* (Fig. 29) be a block of glass with sides *AB* and *CD* parallel. The ray of light *a* strikes the surface *AB* at *l*. This ray is refracted *from the normal* on entering the denser medium and proceeds to *c*. Upon passing from the surface *CD* into a medium of lesser density, refraction again occurs but this time *towards the normal.* Since *AB* and *CD* are parallel, the normals are parallel and the emergent ray is parallel to the incident ray. There is a lateral displacement but not a change in direction.

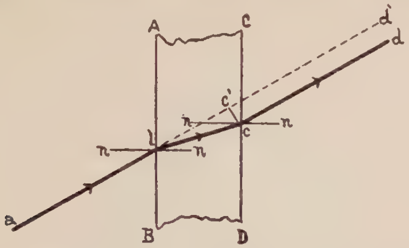


Fig. 29. Refraction in a Medium with Parallel Sides

However, if the sides are not parallel the course of the ray is altered as shown in Fig. 30, in which the course of the light ray is traced through a prism. The ray proceeding from *a* meets at *l* the side of the glass prism *ABC*. It is refracted towards the normal, *n* — *n*, and follows the course indicated by *l* — *c* reaching at *c* the surface of the glass prism *ABC*. On passing out of the prism into air refraction occurs again, but this time away from the normal along the line *cd*. The total angle of refraction is thus equal to the angle at *o*.

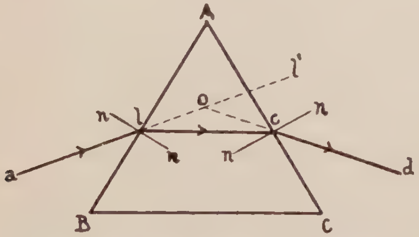


Fig. 30. Refraction in a Prism

$$D = (i - i') - (r - r').$$

Dispersion.—So far we have considered only monochromatic light or light having one definite color, but in practice we do not deal with monochromatic light but with daylight, or at least a light source having a wider range of emission than one narrow band of the spectrum.

When white light is passed through a prism the different rays are not all refracted to the same degree but according to their refrangibility; those of short wave-length, as blue and violet, being refracted to a greater degree than those of longer wave-length, as orange and red (Fig. 31). The angular separation between the constituents of a ray of composite light produced by refraction of the ray in passing through another medium is known as *dispersion.*

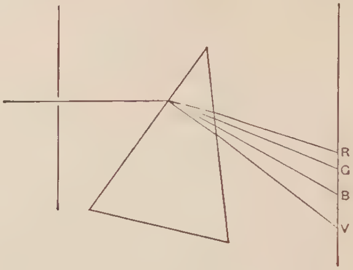


FIG. 31. Dispersion in a Prism

Dispersion was formerly thought to be dependent upon refractive power so that substances having a high refractive power necessarily had a high dispersive power. This is now known to be incorrect and it has become possible to prepare glasses with high refractive power and low dispersion and *vice versa.* Dispersion results in what is termed chromatic aberration, the correction of which is of considerable importance in photographic objectives and will be fully treated in the following chapter on the aberrations of the objective.

Lenses and Image Formation.—There is a very close similarity between a lens and a combination of prisms and in fact we may consider a lens as a prism having an indefinite, or infinite, number of sides. Single lenses are divided into two classes according to whether they are diverging or converging; the former are known as *negative* lenses, the latter as *positive.* The principal forms of converging and diverging lenses are shown in Fig. 32. It will be observed that the former

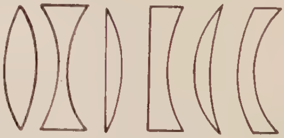


FIG. 32. Principal Forms of Simple Lenses

are thicker at the center than at the edges, while the latter are thicker at the edges than at the center.

The position and character of the image formed by a positive lens will be seen from Fig. 33. In this case AB represents an object

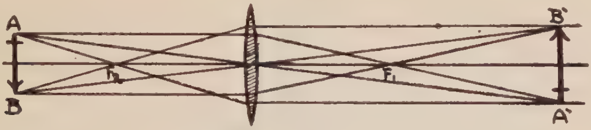


FIG. 33. Image Formation with Positive or Converging Lenses

placed at a distance from the lens which is much greater than the focal length of the lens. For purposes of illustration the course of only three rays proceeding from the object points will be shown. The three rays from A pass through the lens and are refracted so that they intersect one another at A', while the rays from B intersect at B' in a similar manner. Likewise the rays from any point on the line AB on passing through the lens will be refracted and form a corresponding point on the line $A'B'$.[1] The image in this case is real and inverted. The point at which the rays begin is termed the *object point* and the point at which they intersect after having passed through the lens is known as the *image point* or the *focal point,* while the distance from a point in the lens known as the nodal point to the focal point is known as the *focal length.*

From Fig. 34 it will be observed that a negative, or dispersing, lens

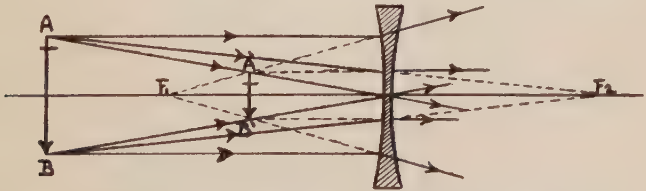


FIG. 34. Course of Light Pencils through a Negative Lens

forms no real image but only a virtual one since the focal point lies between the lens and the object.

Image Formation according to the Gauss Theory.—We owe to Gauss the conception of the nodes and nodal planes of a lens, also called principal or Gauss points after their discoverer. If the positions of these are known, the image can be constructed from the object

[1] We are assuming, of course, a fully corrected lens.

without knowing anything about the actual course traversed by the rays in their passage through the various glasses.

In Fig. 35 are shown the nodes N_2N_1 in a single lens. A ray of light entering at an angle so that it reaches the node at N_2 (node of admission) acts as if it was carried parallel to the axis to N_1 (node of emergence) after which it continues on in a straight line. If we imagine the planes P_2P_2 and P_1P_1 passing through the nodes N_2 and N_1 parallel to the axis, we will see that a ray of light, as *ab,* parallel to the axis on reaching the lens passes undeviated to the plane of emergence and is there bent so that it passes through the focal point. If the lens is reversed the node of admission becomes that of emergence and *vice versa.* Thus every lens may be said to have a front focus and a back focus, the former measured from the node of admission, the latter from the node of emergence, to the focal point.

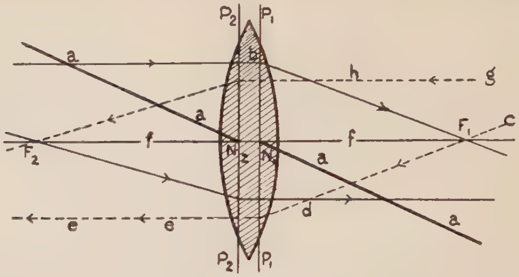


FIG. 35. Image Formation According to the Gauss Theory

In Fig. 36 N_1 and N_2 are the nodes of a lens, P_1P_1 and P_2P_2 the corresponding *nodal planes,* F_1 and F_2 are the front and rear foci respectively, so that F_1N_1 is equal to F_2N_2. Let *ab* represent an object having its lowest point on the lens axis bb_1. The position of point *a* in the image may be found by drawing two rays AP_1 parallel to the axis and thence through the rear focus F_1, the other ray through the front focus F_2 to the plane of admission P_2 and thence parallel to the

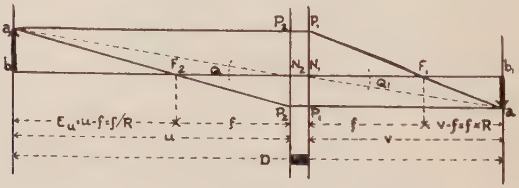


FIG. 36. Image Formation According to the Gauss Theory

axis. The meeting point of these two rays (a_1) is the image point of a. Any other point may be found in like manner, and hence if the position of the nodal planes is known the rays can be traced through the lens whether the curves or glasses of the objective are known or not.

The Position of the Nodes.—The positions of the nodes and nodal planes in a single lens vary with the type of lens. In Fig. 37 the positions of the nodal planes are shown for a number of the common types of single lenses. The light is assumed to be passing from left to right in the direction indicated by the arrow which also indicates the axis of the lenses. N_a and N_e represent the nodes of admission and emergence respectively. When the curves are equal the nodes are centrally placed; when the curves are unequal the nodes lie nearer the side having the greatest curvature. When a lens has a plane surface one node lies at the vertex of the convex surface, while in the case of a meniscus lens one node lies outside of the lens, or "free." In combinations of lenses the positions of the nodes vary considerably. They may lie within the lens itself near the diaphragm, in front of, or behind the lens. When the nodes are situated a considerable distance in front of the lens we secure a great focal length with a short distance between the rear of the objective and the ground-glass. This is the principle upon which the teleobjective is based.[2]

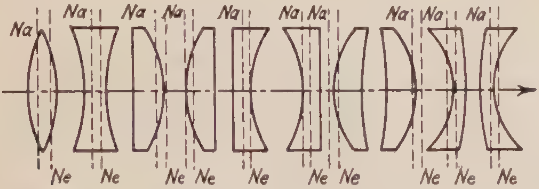


FIG. 37. Position of the Nodes in Common Forms of Simple Lenses

The Principal Focus of a Lens—Focal Length.—When the object is at an infinite distance from the lens so that the incident pencils of light are parallel on entering the lens the focus of the emergent pencil constitutes the *principal focus* of the lens. Since either side of the lens may face the subject, there are two principal foci, both of which are equidistant from the node of emergence but on opposite sides of the lens.

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[2] For a more complete discussion of the nodes and their action see Piper, *The First Book of the Lens,* pp. 31–32 and 45–49.

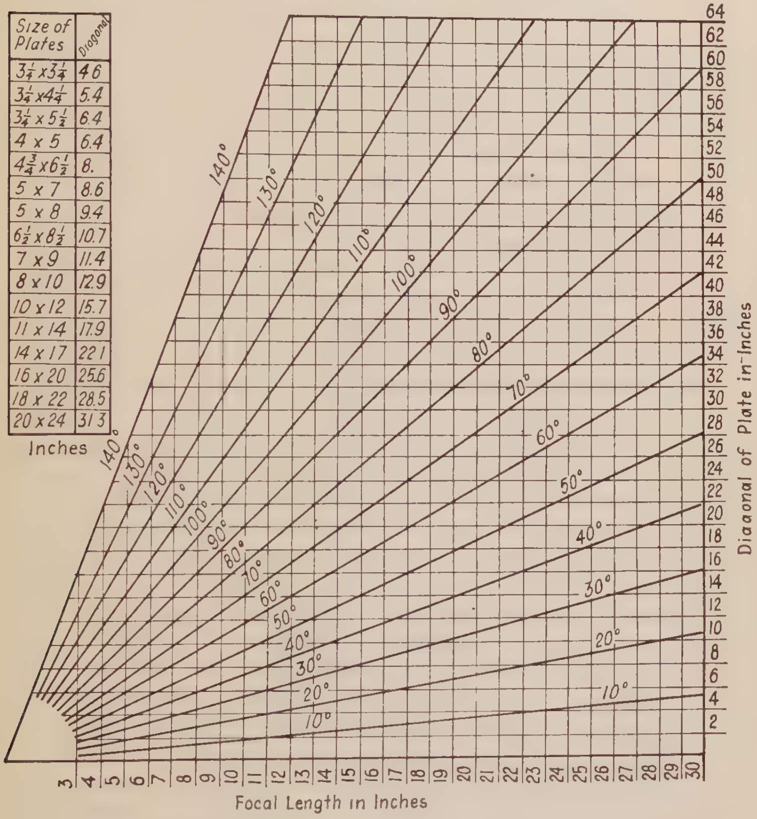
The distance between the back surface of the lens and the sensitive plate constitutes what is called the " back focus." It bears no definite relation to the focal length and its only value is to indicate the bellows extension necessary. The term is now seldom used except in connection with telephoto lenses.

Focal Length and Size of Image.—Assuming a concrete distance between lens and subject, the greater the focal length of the objective the larger the size of the image. Except with very near objects, the size of the image varies directly as the focal length of the objective. Thus with a given distance between lens and subject the image produced by a twelve-inch lens is twice as large as that produced by a lens with a focal length of only six inches. Stated differently, to obtain a given size of image the distance between the lens and the object decreases as the focal length.

While the perspective produced by a lens is always scientifically accurate, regardless of the distance between the lens and the subject, it does not necessarily accord with our established idea of perspective. Owing to the fact that the eye is a long focus instrument and accustomed to viewing objects at a relatively great distance, photographs made with the lens very close to the subject appear to possess violent and unnatural perspective to the eye, so that the result is unsatisfactory to our æsthetic sense even though it may be scientifically accurate.

Perspective is determined entirely by the distance between the lens and the subject and is independent of the focal length of the lens, but since in practice when using a lens having a short focal length the tendency is to get close to the object in order to secure an image of satisfactory size, short focus lenses have gained the reputation of producing violent and disagreeable perspective. There is, however, no actual foundation for this, for if the distance between the lens and the subject is the same the perspective of identical sections of the subject will be the same. Thus if two plates of the same size are exposed, using two lenses of different focal lengths at the same distance from the subject, one plate will include very much more of the subject than the other. However, if this latter is trimmed so as to include the same portion of the subject as the other the two prints will be identical, except in size. Consequently a lens of long focal length gives superior perspective only because the distance between the lens and the subject must be greater for an image of a given size.

The choice of a suitable focal length is governed by the size of the plate and the requirements of the subject. In certain cases short focus objectives must be used in order to include all of the subject from a given viewpoint. In such cases violent and unnatural perspective cannot be avoided and must be accepted. Generally, however, there are no such limitations and the focal length is, within certain limits, a matter of convenience. For all general work it is well to choose a lens the focal length of which is equal to, or slightly greater than, the diagonal of the plate. For pictorial work or portraiture, however, longer focus lenses are desirable and for such work lenses hav-



Size of Plates	Diagonal
3¼ x 3¼	4.6
3¼ x 4¼	5.4
3¼ x 5½	6.4
4 x 5	6.4
4¾ x 6½	8.
5 x 7	8.6
5 x 8	9.4
6½ x 8½	10.7
7 x 9	11.4
8 x 10	12.9
10 x 12	15.7
11 x 14	17.9
14 x 17	22.1
16 x 20	25.6
18 x 22	28.5
20 x 24	31.3

FIG. 38. Table for the Calculation of Angle of View

ing a focal length two, or even three, times the diagonal of the plate are used.[3]

Angle of View.—The angle of view of any objective is the angle subtended by two lines drawn from the node of emergence to the corners of the plate in use. The shorter the focal length of the lens in relation to the size of plate the greater the angle of view and the more of the subject included from a given viewpoint.

It is often of advantage to be able to calculate the maximum angle of view for a given lens on a certain sized plate and to render this a simple matter we have reproduced a chart by which this information can be simply and rapidly secured.

The maximum angle of view possible with any lens depends upon the relation between its focal length and the size of the plate which it will cover with satisfactory definition. For a given size of plate, the shorter the focal length of the lens the greater is the angle of view, while on the other hand, the larger the plate which a lens of given focal length will cover with sufficiently critical definition the greater is its angle of view. Thus a lens of six inches focal length will include a much greater angle if used on a 5 x 7 plate than the 4 x 5 for which originally designed. Most lenses, however, particularly if of high speed, will not cover satisfactorily a plate much larger than that for which they are designed unless considerably stopped down. Some lenses, such as those built on the "Tessar" construction, do not increase in covering power to any extent when stopped down and naturally their angle of view is limited by the plate for which they are designed to cover. A lens made to cover with satisfactory definition a field large in proportion to its focal length is termed a wide angle lens. While no definite rules exist for classifying lenses according to angle, lenses including an angle of less than 45 degrees may be considered as narrow angle; those including angles from 45 to 75 degrees as medium angle, and any lens including an angle above 75 degrees as a wide-angle objective.

Conjugate Focal Distances.—When the distance of the subject is less than infinity, any object point and its corresponding image point are termed *conjugate foci,* and the distance from the object point to the nodal plane of admission and that from the image point to the nodal plane of emergence form what are termed the *conjugate focal distances*. These distances are interdependent and connected by a certain formula.

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[3] For a complete discussion of the fundamentals of perspective see paper by J. C. Dollman in the *Photographic Journal,* 1923, **63**, 315. The same paper will also be found in the *British Journal of Photography,* 1923, **70**, 411.

Let u represent the distance of the object, v that of the image, and f the focal length of the lens. Then

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}.$$

If the values of any two of the above terms are known it becomes a simple matter to find the other from the following:

$$f = \frac{vu}{v + u},$$

$$u = \frac{fv}{v - f},$$

$$v = \frac{fu}{u - f}.$$

From the formula

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

it will be evident that when the distance of the object and that of the image are equal (i.e. u equals v) both distances are equal to $2f$. The image is thus the same size as the object and the term *symmetric foci*, applied by Prof. Thompson, is apt.

The linear ratio of the object and the image is expressed as

$$\frac{\text{Distance of image } (v)}{\text{Distance of object } (u)},$$

but for purposes of calculation it is much simpler to express the ratio in terms of u and f, or v and f (f representing the focal length of the lens). From Fig. 36, representing the principles of image formation according to the Gauss theory, it will be seen that triangles abF_2 and $F_2N_2P_2$ are similar, whence

$$\frac{N_2P_2}{ab} = \frac{F_2N_2}{bF_2}.$$

By construction, N_2P_2 is equal to a_1b_1 and F_2N_2 is equal to f and bF_2 equals $v - f$.

Therefore,

$$\frac{\text{Image}}{\text{Object}} = R = \frac{f}{u - f}.$$

From triangles $a_1b_1F_1$ and $P_1N_1F_1$

$$\frac{\text{Image}}{\text{Object}} = R = \frac{v - f}{f}.$$

Extra Focal Distances.—From the last two formulæ it is evident that calculation is made much simpler when the distance of the object or the image is reckoned from the front or rear focal point respectively. These distances which are therefore $u - f$ and $v - f$ are known as the *extra focal distances.* The extra focal distance of the object is denoted by E_v and that of the image by E_u.

Therefore,

$$E_v = v - f = fR,$$

$$E_u = u - f = \frac{f}{R}.$$

In other words, the extra focal image distance is equal to the focal length of the lens *multiplied* by the ratio of image to object, while the extra focal object distance is equal to the focal length *divided* by the ratio of image to object.

Calculations of the conjugate distances can be made quite simply by considering the distance between the image and the object to be divided into five separate distances. These are:

1. The extra focal distance—focal length multiplied by the number of times of reduction or enlargement.
2. One focal length.
3. The nodal space—generally negligible.
4. One focal length.
5. The extra focal distance—focal length divided by the number of times of reduction or enlargement.

In the case of reduction (1) and (2) are on the object side of the lens, but when enlarging (5) and (4) are on the object side of the lens and (1) and (2) on the image side. When copying same size (1) and (5) are alike and are equal to one focal length, so that the whole distance from object to image is equal to four focal lengths, if the nodal space be neglected.

The above are the fundamental formulæ covering the relation of the conjugate foci when enlarging or reducing and almost any required calculation relating to the sizes and distances of object and image may be worked out from the formulæ above.[4]

Theory of Depth of Focus.—In explaining the theory of depth of focus, more properly termed depth of field, use will be made of the illustration developed by Moritz von Rohr.[5]

In Fig. 39 let $O_3O_2O_1$ represent an object, parts of which are at different distances from the lens L. For the sake of simplicity the latter is represented without the nodes necessary for a complete representation of its action. Suppose the lens to be focused on O_1, a point image I_1 will then be formed on the focussing screen or sensitive plate. With the focussing screen, or the sensitive plate, at this point it is clear that the image of O_2 is formed at I_2 *behind* the screen and that of O_3 at I_3 in *front* of the screen. In other words the position of the image point varies with the distance of the object point and the lens cannot produce a point for point image upon a plane subject unless the subject itself is a plane surface. When this is not the case, rays proceeding from object points nearer to, or farther from, the lens than the plane focussed for do not produce a point

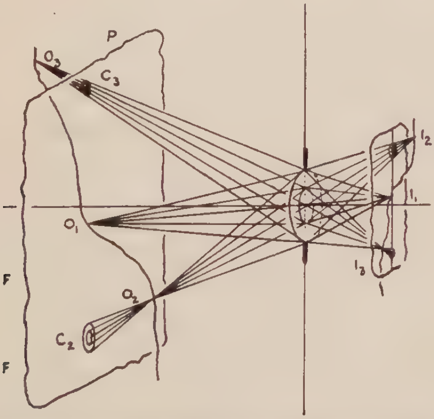

FIG. 39. Graphic Illustration of the Principle of Depth of Focus. (Von Rohr)

image on the focussing screen but instead a circular disk. However, owing to the fact that the eye has its limits of definition and cannot appreciate critical sharpness, these disks may appear as point images to the eye if their diameter is less than a certain size which is termed the *circle of confusion.* The circle of confusion thus represents a circle of the largest diameter possible without producing perceptible unsharpness to the eye. The largest circle which will appear as a point to the eye is a variable dimension depending upon the distance from which the photograph is viewed. It is found that at a distance of 12 inches, which is a normal viewing distance for prints up to approximately 8 x 10, a circle with a diameter of not more than 1/100 of an inch will appear as a point to the normal eye. Consequently this has to a certain extent been adopted as a standard for satisfactory definition in photographic work. It is to be noticed that this value applies to the finished print but not necessarily to the original negative. For instance when a negative is enlarged the standard requires to be reduced in proportion to the degree of enlargement in order that the circles of the enlarged print may not exceed the maximum permissible diameter. Where negatives are to be subsequently enlarged the circle of confusion should not exceed 1/250 of an inch in diameter and in cinematography still less departure from critical sharpness is allowable: in this latter case the diameter of the circle of confusion allowable is about 1/600 of an inch. Hence, the better plan of expressing the circle of confusion is in terms of the viewing distance, as adopted by Continental writers, rather than the adoption of an arbitrary standard.

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[4] Numerous formulæ for the calculation of the various problems pertaining to scale in optical reproduction were given by Mr. George E. Brown in the *British Journal of Photography* for 1921, 68, pp. 702–705.

[5] *Zur Geschichte und Theorie des Photographischen Teleobjectiv.* 1897. Also *Eder's Jahrbuch* for 1906.

According to the latter view, the permissible circle of confusion is not a definite value, but a variable, which depends upon the distance from which the print is viewed. It is found that any object, regardless of size, will appear as a point to the eye when viewed at a distance equal to, or greater than, 3,400 times its diameter. This is equivalent to the very small angle of 1 minute (or a 5,400 part of a right angle). In order to be sharply perceived the angle must be at least 5 minutes, hence objects subtending angles of 1′–4′ are perceived more or less distinctly and appear practically sharp to the eye. This view of the variable standard of the admitted disk of confusion has much to commend it, and in view of the widespread practice of enlarging from small negatives it would probably be better if it were universally adopted and the older method of an arbitrary standard abandoned.[6]

Factors Controlling Depth of Focus.—The factors which control depth of focus are:

1. The focal length of the objective.
2. The aperture of the lens.
3. The distance of the plane in sharp focus.
4. The permissible diameter of the circle of confusion.
5. The presence of spherical aberration.

The extent of field in sharp focus, other conditions remaining constant, is greater the shorter the focal length of the lens. The depth of field varies inversely as the square of the focal length, if near objects be excepted. It is for this reason that fixed-focus cameras and cameras focussed by scales are generally fitted with lenses of the shortest focal length consistent with the size of image required for the plate in use.

Increasing the rapidity of the lens reduces quite rapidly the depth of focus. Thus with a lens of six inches focal length focussed on infinity, all objects up to 20 feet of the camera will be sharp if the lens is used at F/16. If the lens is opened up, however, say to F/4, then the depth of focus will only extend from infinity to within 75 feet of the camera. The difference in the extent of field in sharp focus at different apertures is even more noticeable when a plane comparatively near the camera is focussed for.

From what has already been said it will be evident that depth of focus in any given case will depend considerably upon the standard of definition adopted as satisfactory. Thus the depth of focus will be much greater if a circle of confusion equal to 1/100 of an inch is accepted as satisfactory in place of 1/250 inch or less. For contact prints up to 8 x 10 the former standard is satisfactory but when smaller negatives are enlarged up to that size the latter standard, or an even higher value, must be adopted if the resultant enlargement is to appear critically sharp on inspection at the normal viewing distance of 12 inches.

The presence of spherical aberration increases the *apparent* depth of focus since it destroys critical definition and as a result there is no clear dividing line between that portion of the subject which is sharp and that which is unsharp. An excellent example of this is seen in the modern soft-focus objectives which have greater depth of focus than other objectives of the same focal length and aperture because the difference between the portions in focus and those slightly distant from the plane focussed on is not so readily noticeable, and also because a circle of confusion greater than 1/100 of an inch is accepted as permissible. If the depth of such an objective be considered from the latter viewpoint, it is quite possible that it might have no depth whatsoever since the circles of confusion would nowhere be less than 1/100 of an inch in any part of the field.

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[6] For a full discussion of the two methods and the factors on which the same are based see "Theory and Practice of Depth of Focus" by George E. Brown in the *British Journal of Photography*, 1922, p. 476 et seq.

The Intensity of the Image.—The intensity of the image formed by the lens is naturally a matter of considerable importance since on it depends the time of exposure required to impress the image on the sensitive film or plate. It is evident that where other conditions are constant the times of exposure with any two lenses will be in inverse proportion to the intensity, or brilliancy, of the image which they project on the sensitive material. Neglecting for the moment losses in the incident light due to absorption or reflection by the glasses of which the lens is composed, the intensity of the image *on the axis* is the volume of light admitted divided by the area over which it is spread. The intensity of the image at points removed from the axis is naturally dependent to a certain extent upon the optical performance of the lens, but the intensity of the image on the axis is governed solely by the volume of light passing through the lens divided by the area over which it is spread in order to form the image.

The volume of light admitted is of course dependent upon the area of the diaphragm aperture. Since the areas of circles are to one another as their diameters squared the volume of light transmitted by any two lenses is directly proportional to their diameters squared. Thus the volumes of light passed by any two lenses having an aperture of d_1 and d_2 are to one another as $d_1^2 : d_1^2$.

In case the light from d_1 and d_2 is spread over the same area, in other words the two lenses form an image of the same size, the intensity of the image will be directly proportional to d_1^2 and d_2^2. Thus the intensity of the image is proportional to d^2.

Suppose, however, a lens with an aperture of diameter d_1 (Fig. 40) has a focal length of f_1. If O be a luminous point in an object at such a distance from the lens that the incident rays are practically parallel, then the image will be formed at the principal focus of the lens f_1 and may be represented by F_1F_1. Now suppose this lens is replaced by another having the same aperture but with a focal length twice as great as f_1 so that $f_2 = 2f_1$. Then the image F_2F_2 will be twice as large as that of F_1F_1. Hence

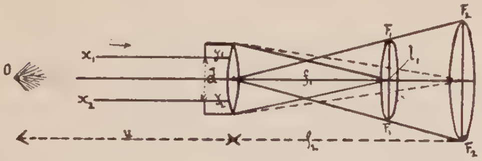

Fig. 40. Intensity of the Optical Image. (Brown)

$$\frac{\begin{pmatrix}\text{Diameter}\\ F_1F_1\end{pmatrix}}{f_1} \quad \frac{\begin{pmatrix}\text{Diameter}\\ F_2F_2\end{pmatrix}}{f_2}. \tag{1}$$

But the areas of the images F_1F_1 and F_2F_2 are to one another as the squares of their diameters, hence we may write (1) as follows:

$$\frac{(F_1F_1)^2}{f_1} \div \frac{(F_2F_2)^2}{f_2}. \tag{2}$$

Thus the areas of F_1F_1 and F_2F_2 are proportional to the corresponding focal lengths squared. As the aperture, d, is constant, the intensity of the image is thus inversely proportional to the focal length squared, or f^2.

Hence we have

$$\frac{\text{volume of light proportional to } d^2}{\text{area of image proportional to } f^2};$$

the intensity of the image, then, is represented by the expression

$$d^2/f^2. \tag{3}$$

If this is written $(d/f)^2$, the d/f expresses the ratio between the aperture and the focal length and is termed the *aperture ratio.*

Speed of Lenses—Systems of Diaphragm Notation.—The aperture ratio d/f affords a convenient means of expressing the speed of lenses. It is evident that the intensities of two lenses are to one another as the squares of their aperture ratios. Thus if the aperture ratios of two lenses are represented as d_1/f_1 and d_2/f_2 respectively, the relative intensities are as

$$(d_1/f_1)^2 \div (d_2/f_2)^2.$$

Hence if the intensities of the image are expressed by the aperture ratios d/f, the relative intensities may be found by squaring both ratios and finding the relation between the squares.

It is not customary, however, to mark lenses according to the intensity of the image, but according to the exposure required, which is of course in inverse proportion to the intensity, for as the brilliancy of the image is increased the time of exposure is proportionately decreased. Accordingly the diaphragm numbers on lenses represent not the intensities but rather the reverse of these or the " slowness " of the lens.

In 1881 a committee of the Royal Photographic Society of Great Britain advised that an aperture ratio of 1 : 4 be adopted as standard and a series of aperture ratios chosen so that each successive aperture would have an *area* one half that of the preceding, in order that the exposure required for each successive aperture be double that for the one immediately preceding and avoiding altogether the necessity of squaring the aperture ratios in order to find the relative exposures for the various apertures.

Since a circle of one half the area has a diameter equal to $1/\sqrt{2}$ the series of ratios becomes

$$\frac{d}{f} = \frac{1}{4} \quad \frac{1}{5.6} \quad \frac{1}{8} \quad \frac{1}{11.3} \quad \frac{1}{16} \quad \frac{1}{22.6} \quad \frac{1}{32} \quad \frac{1}{45} \quad \frac{1}{64}$$

or in terms of f/d

4 5.6 8 11.3 16 22.6 32 45 64

Relative exposure required

1 2 4 8 16 32 64 128 256

It was further advised that in the case of lenses having a maximum aperture ratio intermediate in value between any of the above the F/number, obtained by dividing the aperture by the focal length, be marked upon the mount. Accordingly we have lenses bearing F/numbers of $F/4.5$, $F/4.7$, $F/6.3$, $F/6.8$, etc. The relative exposure required for any of these F/numbers may be found by squaring it and the nearest F/number in the series and dividing one by the other.

Effective Aperture.—In the above sections the area of the aperture has been assumed to be the same as the actual area of the diaphragm, *d*. This is correct where the diaphragm is in front of the lens as in such cases the diameter of the pencil of light which can pass through the lens is obviously equal to the diameter of the diaphragm. In the case of photographic lenses having the diaphragm between the components, the diameter of the pencil of light which passes through the lens may be much greater than the actual diameter of the aperture, owing to the fact that the front lens acts as a condenser and converges the incident rays so that a pencil larger than the actual aperture may pass through. The diameter of the pencil which is converged so as to pass through the diaphragm constitutes what is termed the *effective aperture.*

A practical illustration of the difference which may occur between the effective and the actual aperture due to the converging action of the front component was given some years ago by Dr. Zschokke for the Goerz Dagor, a double, symmetrical anastigmat the halves of which are identical. When the front component is used alone in its normal position in front of the diaphragm the effective aperture due to the "coning" action of the front lens is *F*/11.3. When the rear combination is used behind the diaphragm the effective aperture coincides with that of the diaphragm and is reduced to *F*/13.6. The brightness of the image is therefore nearly one and a half times greater in the first case than in the second, a difference due solely to the converging action of the front component.

The difference in the effective and the actual aperture may be even greater with lenses of different design. Thus in the Aldis *F*/6 lens the actual diameter is only about .87 of the effective aperture.

It is evident upon further consideration of the matter that the effective aperture will vary according to which end of the lens faces the subject unless both components are identical. In the case of the Aldis *F*/6 the components are dissimilar and the aperture when the lens is reversed, with regard to the subject, is only *F*/6.9 or for all practical purposes *F*/7.

With a lens having the diaphragm in front, the effective aperture varies to a certain extent with the distance of the subject, owing to the fact that the incident pencil of light is divergent rather than parallel. This effect, known as *inconstancy of aperture*, is so small in most cases that for practical purposes it may be disregarded.

It is evident that it is the effective, rather than the diaphragm, aperture which must be considered in calculations regarding the intensity of the image. Hence it is more accurate to say that the aperture ratio d/f is

$$\frac{\text{the effective aperture}}{\text{focal length of lens}}$$

than simply the aperture divided by the focal length as before.

Visual methods of determining the effective aperture have been described by C. Welborne Piper and by Jobling and Salt,[7] but perhaps the method most generally useful consists in focussing the lens on a very distant object and replacing the ground-glass by a card, or other thin opaque material, pierced with a pinhole on the optical axis. A lighted candle, or electric bulb, is then placed next to the pinhole. It is evident that since the latter is at the focus of parallel rays, light from a source in this position will emerge from the lens as a parallel pencil of a diameter equal to the effective aperture. The circle corresponding with the effective aperture may be obtained by pressing a scrap of bromide paper against the lens and exposing, or by outlining the same on a sheet of thin paper.

Loss of Light in Lenses Due to Absorption and Reflection.—The statement is often made that all lenses require identical exposures when used at the same relative aperture, but this is not strictly true as owing to the differences among lenses in the amount of light lost from absorption and reflection by the glasses of which the objective is composed, the actual intensity of the images may vary considerably, notwithstanding the fact that all are marked with the same F/number.

The amount of light lost by absorption and reflection in photographic objectives is greater than might be at first supposed. The question has been several times investigated [8] and it has been shown conclusively that the loss varies from 10 per cent in the simplest single lens to nearly 50 per cent in the case of many of the more complex lenses and that few modern anastigmats transmit more than two thirds of the incident light.

The losses from absorption do not amount to as much as those due to reflection. For this reason it is desirable to keep the number of reflecting surfaces in a lens to the minimum. Dr. Zschokke showed that of two lenses with an aperture of *F*/6.8, the one a symmetrical doublet having four reflecting surfaces (Dagor), the other composed of four single lenses having 8 glass-to-air surfaces (Syntor), the light transmitted by the former amounted to 88.77 per cent to 65.16 per cent for the latter. Consequently the first lens (Dagor) at an aperture of *F*/7.5 is actually as rapid as the second (Syntor) at its full aperture of *F*/6.8.

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[7] Jobling and Salt, *Brit. J. Phot.*, 1922, **69**, 108. Piper, *Brit. J. Phot.*, 1917, **64**, 272.

[8] Cheshire, *Brit. J. Phot.*, 1912, **59**, 597, 645. Zschokke, *Brit. J. Phot.*, 1912, **59**, 823. Odencrants, *S. I. P.*, 1925, **5**, 87. Forch & Lehrmann, *Kinotechnik*, 1928, **10**, 3. Moffett, *Phot. J. Amer.*, 1920, **59**, 44. Nutting, *Phot. J.*, 1914, **54**, 187. Goldberg, *Der Aufbau des Photographischen Bildes*; *Enzyk. der Photographie*, Hft. 99, pp. 23–43. (W. Knapp, Halle A/S. 1924.)

The percentage of light transmitted by representative types of modern anastigmats has been measured by Odencrants and more lately Forch and Lehrmann. The following table summarizes the result of their investigations:

LOSS OF LIGHT IN PHOTOGRAPHIC OBJECTIVES

Objective	Marked *F*/value	Transmission	Effective *F*/value
Ernostar	*F*/2	46.6%	*F*/3.1
Rüo	*F*/2	58.1%	*F*/3.26
Kinoplasmat	*F*/1.5	38.7%	*F*/2.82
Planar	*F*/4.5	52.2%	*F*/5.65
Tessar	*F*/3.5	60.0%	*F*/4.64
Tessar	*F*/4.5	63.5%	*F*/5.94
Dogmar	*F*/4.5	52.7%	*F*/6.39
Aviar	*F*/4.5	49.7%	*F*/6.65
Collinear	*F*/6.3	53.4%	*F*/8.67

From what has been said, it is evident that the *F*/number is by no means an accurate indication of the speed of the lens, as it does not take into account the losses due to absorption and reflection and these, as we have seen, are sufficient to cause considerable differences in the intensity of the image. Perhaps as time goes on we will find a more efficient method based, perhaps, upon the time required to produce a definite amount of photochemical action. At any rate, regardless of the angle from which the matter is attacked, a method of expressing speed which takes into consideration the loss of light due to reflection and absorption would certainly be a step in the right direction.

Variation in the Relative Aperture with Distance of Subject.—We have seen before that the size of the image varies with the distance of the object from the lens. As the size of the image increases as the object is brought nearer the lens, so does the conjugate focal distance, v, increase. When the distance of the object is sufficiently great, so that the rays of the pencil of light entering the lens are practically parallel, the conjugate focal distance, v, is equal to the focal length, f. The intensity of the image is then expressed as d^2/f^2. However, if the object point is brought closer to the lens, the conjugate focal distance, v, is no longer equal to f, but becomes progressively greater as the object nears the lens. It is evident then that as long as the aperture remains constant, the intensity of the image will be represented by d^2/v^2 rather than d^2/f^2. As the conjugate distance varies with the distance of the object, it is apparent that the intensity of the image, and therefore the time of exposure, will vary with the distance of the object point.

In the vast majority of cases where the object is relatively distant from the lens, a condition applying to practically all exterior work and embracing the larger number of subjects, the variation in the aperture ratio is so small as to be practically insignificant in practical work, but in photographing very small objects, copying, enlarging, lantern slide reduction and similar work the variation becomes a matter of considerable importance and must be taken into consideration in calculating the time of exposure. There are two ways in which this may be done. The distance from the rear nodal plane to the sensitive plate or film may be measured and the $F/$value calculated from d^2/v^2, but as this method requires a knowledge of the position of the rear nodal plane and the effective aperture it is not as convenient as the second method. This consists in basing the exposure on the nominal $F/$value as marked upon the lens and increasing it according to the camera extension, v, by multiplying by v^2/f^2.

However, as these calculations are usually required only in copying and similar work, it becomes more convenient to draw up a table taking as a standard the exposure required for copying full size (4 times that required with a subject 24 times the distance of the focal length) and entering the result of the calculation for relative exposures for various extensions by the scale of reduction produced. The following table of the relative exposure for varying proportions of the image to the original was calculated by Mr. W. E. Debenham several years ago and will be found very convenient in indicating the correction in exposure to be made when copying on various scales. Other methods of making these calculations are given in the chapter on lantern slides and copying.

Proportion of Image to Original (Linear)	Proportionate Exposures	Exposures Proportioned to that Required when Copying Same Size
1/30	1.07	.27
1/20	1.10	.28
1/10	1.21	.3
1/8	1.27	.31
1/6	1.36	.34
1/4	1.56	.39
1/2	2.25	.56
3/4	3.06	.76
1 (Same Size)	4	1
2	9	2.25
3	16	4
4	25	6.25
5	36	9
6	49	12.25
7	64	16
8	81	20.25
9	100	25.
10	121	30.25
11	144	36
12	169	42.25
13	196	49
14	225	56.25
15	256	64
16	289	72.24
17	324	81
18	361	90.25
19	400	100
20	441	110.25

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Wallon—Choix et Usage des Objectifs Photographiques.

CHAPTER IV

ABERRATIONS OF THE PHOTOGRAPHIC OBJECTIVE

Introduction.—In a perfect lens image every point in the object will be represented by a corresponding point on the flat surface receiving the image. It is impossible to realize this ideal and still preserve the speed required for photographic purposes because of the defects or aberrations to which lenses are subject. The more important of these aberrations are:

Chromatic aberration,
Spherical aberration,
Coma,
Curvature of field,
Distortion,
Unequal illumination,
Astigmatism.

We will consider at some length the causes, effect on the image and manner of correction of each of these.

Chromatic Aberration.—Chromatic aberration is a defect caused by the dispersing properties of glass which prevents a lens from transmitting white light from a point of the object to a similar point of white light in the image. In other words the ray of light on passing through the lens is broken up into its component colors, the foci of which do not coincide but are situated at varying distances along the axis.

The violet rays come to a focus at F_v (in Fig. 41), the red at F_r and the blue, green, yellow, and orange rays to intermediate points between F_v and F_r. The image formed at F_v is that produced by the violet rays, that at F_r by the red rays but in each case there will be superimposed on this image the images produced by the other colors, so that no matter where the sensitive plate is placed between F_v and F_r we cannot secure a sharp image because of the intermingling of the other images, which are not brought to the same focus.

In the early days of photography when emulsions were practically insensitive to any but the violet and blue rays, it was the common practice to rack the lens towards the plate a distance sufficient to place the plate at the focus of the violet image. As the plate had little or no sensitiveness for the less refrangible rays, the definition was not seriously affected. With modern color-sensitive materials, this is no longer the case.

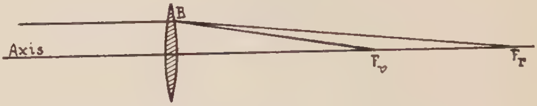

Fig. 41. Chromatic Under Correction

With a converging or positive lens, chromatic aberration takes the form shown in Fig. 41, where v is the focus of the violet and y of the yellow rays respectively. This is known as *chromatic undercorrection.*

With a diverging or negative lens, we have a different case, which is represented in Fig. 42 and is termed *chromatic overcorrection.*

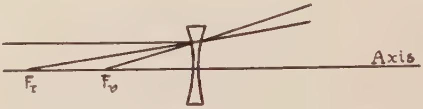

Fig. 42. Chromatic Over Correction

The method employed in correcting chromatic aberration will now be evident. When a positive and a negative lens of equal power are combined the combination is rendered achromatic. That is to say, it transmits white light as such, but on the other hand the two lenses being of equal but opposite power neutralize one another so that the light rays are not refracted and consequently no image can be formed. However, if the positive lens has a slightly higher refractive index than the negative lens and the latter a higher dispersion than the former, the dispersions may be neutralized without destroying the refracting power so that the lens may be at once convergent and achromatic.

For the sake of simplicity we have been considering only two colors, violet and yellow, assuming that if these are brought to the same common focus the other colors will be brought to the same point. However, this is not the case and with two pieces of glass it is only possible to bring two colors to a common focus. This difficulty is due to the fact that the relative dispersions of glass are not the same throughout the spectrum. Thus the total dispersion of one glass may be twice that of another and lenses from the two glasses may bring any pair of colors together but will not bring the other colors to the same focal point unless the dispersion of one glass is double that of the other *in every part of the spectrum.* In most glasses, however, the relative dispersion is not constant and the degree of dispersion varies with the wave-length of the light as shown in Fig. 43. This is known as the "irrationality" of dispersion.

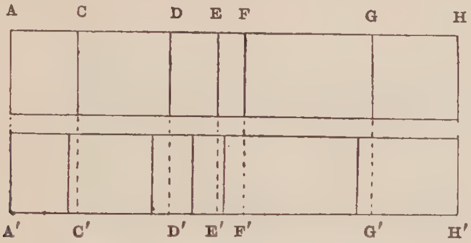

FIG. 43. Irrationality of Dispersion

The pair of colors chosen for exact coincidence of focus depends upon the purposes for which the lens is designed. Thus in instruments for visual use, as the microscope, the green and orange are generally chosen because they, together with the yellow which lies between them, are the brightest colors to the eye. However, since the plate is more sensitive to the ultra-violet, violet and blue than to light of longer wave-length, the colors chosen for photographic purposes are the violet, which lies midway between the very active ultra-violet and the slightly less active blue, and yellow, which is used for focussing on account of its luminosity.

For all ordinary purposes lenses corrected for only two colors are satisfactory, since the other colors are either brought very close to the common focus or are so much less active that they do not affect the sensitive plate sufficiently to destroy the definition. A lens corrected for two colors is termed an *achromat,* or is said to be *achromatic.* The colors which are not brought to an exact focus form what is termed the *secondary spectrum.*

In three-color process work it is necessary that three colors, instead of two, be brought to the same focus in order that the three negatives may be equally sharp and of the same size. By the introduction of other glasses with the proper calculations it has become possible to produce lenses in which three colors are brought to the same focal point. These are referred to as *apochromats,* or are said to be *apochromatic.* These are generally much slower than other lenses and are not used to any considerable extent for work other than that for which they are designed, since achromatic correction is sufficient for all ordinary photographic purposes.

Spherical Aberration.—Spherical aberration results from the use of lenses, the surfaces of which are spherical. In a lens with spherical surfaces the rays of light near the margin of the lens are refracted differently from those nearer the axis so that the two do not come to a focus at the same point. If it is a converging lens, the marginal rays are brought to a focus closer to the lens than those nearer the axis, while in a dispersing lens the virtual focus is greater for the marginal rays than for the rays nearer the axis. The converging lens is said to be spherically *undercorrected;* the dispersing lens *overcorrected.*

Fig. 44 represents the condition of *spherical undercorrection.* The parallel rays h_1, h_2, h_3, h_4 on passing through the lens form image points at different distances from the lens, those passing through the margin of the lens having a shorter focus than those passing through the lens at a point nearer the axis. By taking the distances of the rays from the axis as ordinates and the distances from the image point for the axial zone as abscissæ we may construct a curve showing the degree of *undercorrection* present.

Bearing in mind that a negative lens forms only a virtual image, parallel rays entering from the right will form virtual image points at different distances to the right of the lens as shown in the dotted lines of Fig. 44. By using h_1, h_2, h_3, h_4 as ordinates and the image distances as abscissæ, in the same manner as before, a curve can be constructed which shows the degree of *spherical overcorrection.*

The method of correction consists in compensating the undercorrection of a positive lens by combining it with a negative lens whose overcorrection is sufficient to cause the marginal pencils to come to a focus at the same point as the axial pencils. It will be remembered that chromatic correction was corrected in a similar manner by balancing two lenses of opposite errors. To correct for chromatic aberration it is necessary that the lenses possess certain definite focal proportions. Now it is possible to make a lens with a definite focal length in rection cannot be made absolutely alike. Fig. 44 shows a lens which have the relative focal lengths necessary for chromatic correction and at the same time make them of such shapes as will correct spherical aberration. Thus since chromatic aberration may be said to depend on the focal length of the lenses and spherical aberration on their shapes it is possible to correct both of these errors in the same combination simultaneously.

In practice it is virtually impossible to completely correct an objective for spherical aberration since the curves of over- and undercorrection cannot be made absolutely alike. Fig. 44 shows a lens which has the spherical aberration corrected for the center and a zone near the margin. The rays h_2 and h_3 do not come to the same focus so that by taking their distances and the distance of the rays from the axis, according to the methods used above, it is possible to construct a curve showing the amount of spherical aberration remaining in the combina-

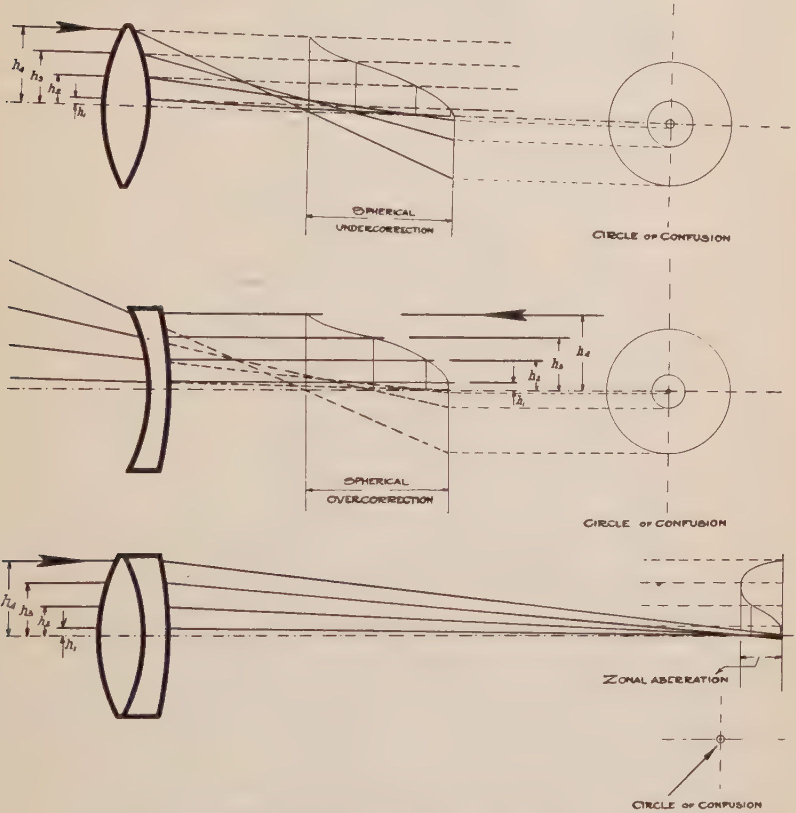
h_4
h_3
h_2
h_1
SPHERICAL UNDERCORRECTION
CIRCLE OF CONFUSION
h_4
h_3
h_2
h_1
SPHERICAL OVERCORRECTION
CIRCLE OF CONFUSION
h_4
h_3
h_2
h_1
ZONAL ABERRATION
CIRCLE OF CONFUSION

FIG. 44. Spherical Aberration

tion. Perfect correction would be indicated by a straight line but a certain amount of uncorrected spherical aberration remains in even the very highest grade lenses.

Coma.—Coma is the name applied to the spherical aberration of the oblique rays of light on passing through the lens.

From Fig. 45 it will be seen that the course of oblique rays on passing through a lens is completely unsymmetrical. The rays below the axis of the lens are bent more sharply than those above the axis and thus do not meet in a common point but in a *series* of points. Assuming that the sensitive plate is placed at any one of these points of intersection it is evident that we will not secure an exact image point because all of the rays from the corresponding point in the object are not refracted to the same point in the image. In practice instead of a sharp, well-defined point we secure a small pear-shaped spot which seriously affects critical definition.

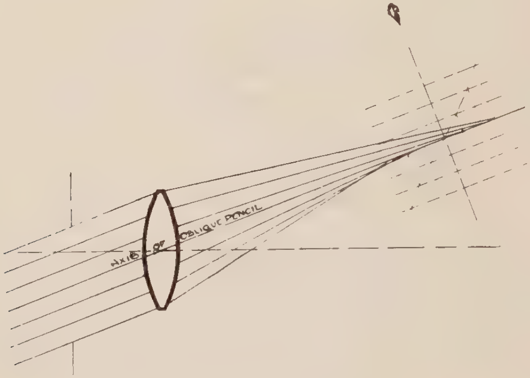

FIG. 45. Coma. (Kellner)

In Fig. 46, *A* represents the condition known as *outward coma,* the points of the pear-shaped blur facing away from the axis of the lens. If the position of the lens is reversed we have the reverse effect because the upper ray is refracted the most and the effect of *inward coma* is produced. In this case, as the name indicates, the points face the axis.

The amount of coma present in any objective may be shown graphically by a curve obtained in much the same manner as that which we have previously used as an expression for spherical aberration (Fig. 45). This curve shows the distances of the different points of intersection measured along the axis of the oblique pencil from a plane laid through the ideal image point. Perfect correction is indicated by a straight line, but as coma is one of the most difficult aberrations to remove, the line is in practice always slightly curved, for while great strides have been made in overcoming coma, most modern lenses still show measurable amounts.

Coma is corrected in two ways: by the use of a diaphragm and by compensation. From the illustration it will be seen that a diaphragm placed in front of the lens will remove the majority of the oblique pencils of light and thus reduce the amount of coma. The principal method, however, is by neutralizing the inward coma of one lens with an equal amount of outward coma in another lens. If the two lenses in Fig. 46 are combined the outward coma of one is neutralized by the inward coma of the other and if we assume that the amounts of coma present are equal but opposite powers, it is evident that complete neutralization will take place and that the pair as a whole will be free from coma. Further, since it can be proved that opposite forms of coma are given by simply reversing the curvatures of the lens, it is possible to find an intermediate form of lens which is practically free from coma—a discovery utilized by Mr. H. Dennis Taylor in the well-known Cooke triplet objective.

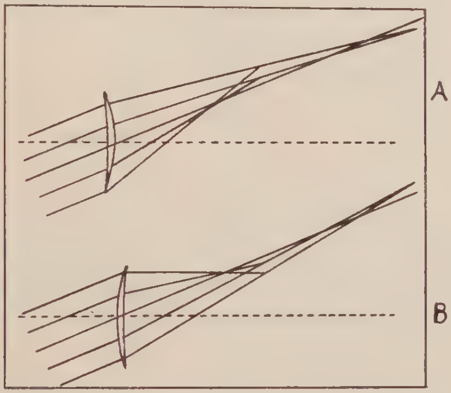

Fig. 46. Two Forms of Coma. (Piper)

Curvature of Field.—As the surfaces of the sensitive materials employed in general photography are always plane, it is essential that the image formed by the lens likewise be plane in order that sharp definition be secured over the entire plate. This means that the focus of the oblique pencils of light must lie in the same plane as that of the axial pencils. With all single lenses, however, the focal points of the oblique and axial pencils do not lie on the same common plane but on a curve.

With a positive lens (Fig. 47) this curve is concave to the lens since the axial pencils come to a focus at *a* while the focus of an oblique pencil is at *b* rather than at *c*. When the image curve is concave to the lens the condition is known as *positive* curvature of field. It may also be referred to as *under correction* for curvature of field.

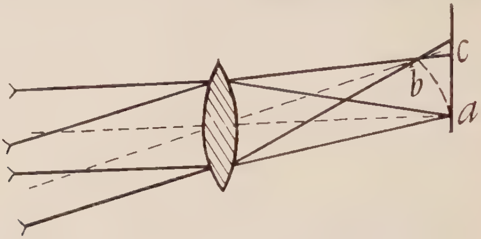

Fig. 47. Curvature of Field. (Under Correction)

With a negative lens (Fig. 48) the image field is again curved but this time the curve is convex to the lens and the condition is then known as *negative* curvature of field or sometimes as *over correction* for curvature of field.

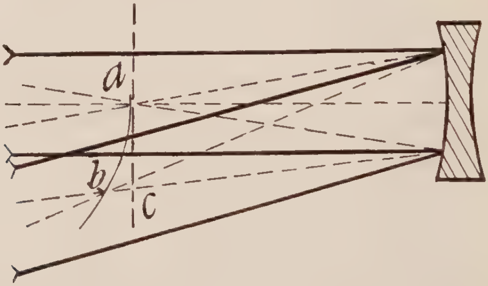

Fig. 48. Curvature of Field. (Over Correction)

The actual curvature of the image with an uncorrected lens varies with the radii, glass, thicknesses of glass, separation of the component lenses and with the position of the diaphragm and the distance of the object. The curvature of field of a positive lens may be removed by the introduction of a negative lens if the latter is sufficiently powerful and placed at the proper distance. A perfectly flat field is not to be expected in any lens, however; least of all in one of the older constructions, such as the Petzval portrait lens, or the aplanat, where a compromise must be made between curvature of field and astigmatism. In the anastigmats the curvature of field is less pronounced, but even here all objectives show a slight departure from absolute flatness, but the degree of positive or negative curvature is, in the majority of cases, not sufficient to cause serious trouble.

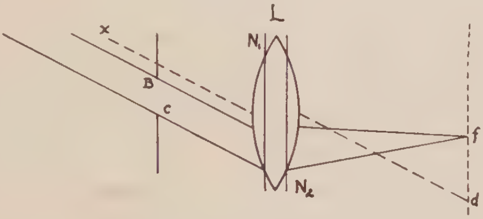

FIG. 49. Distortion

Distortion.—There are several kinds of distortion but the only one which we intend to discuss in this place is that due to the inability of the objective to reproduce a straight line as such. It is a very objectionable fault in a number of branches of work such as copying, architectural photography and the majority of all scientific work.

The following diagram will help in explaining without the aid of mathematics the general manner in which distortion is produced. Let N_1 and N_2 (Fig. 49) be the nodal planes of admission and emergence respectively of the lens L, and let BC be a diaphragm placed at some distance in front of the lens. The solid lines represent parallel rays of light from a distant object passing through the diaphragm, BC, to the lens, L, and from thence to a focus at f. Let xN and xN' be parallel lines drawn through the nodal planes of incidence and emergence. Let d be the point on the image plane where the line $N'd$ intersects it. d is therefore the true position for the rays, but owing to the fact that a simple lens bends the marginal rays more than the central ones, the image point lies not at d, its true position, but at f, a point nearer the center.

When the diaphragm is placed before the lens we have what is termed *barrel distortion,* a state of affairs represented in Fig. 50. When the diaphragm is placed behind the lens the form of distortion is reversed and is in this case known as *pincushion distortion.* It is preferable, however, to call the first *negative* and the second *positive* distortion.

The method employed in correcting distortion is to combine two equal but opposite errors. It has been pointed out that with the diaphragm before the lens we have negative distortion, while when the diaphragm is placed behind the lens we have positive distortion. Then if we use two separate combinations, placing the diaphragm at the proper point between the two, the positive error of one will be neutralized by the negative error of the other and a rectilinear or non-distorted image will be produced.

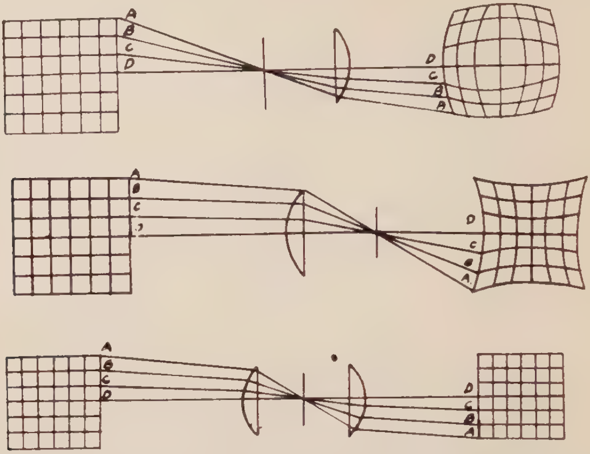

Fig. 50. Upper: Negative or "barrel-shaped" distortion. Center: Positive or "pincushion" distortion. Lower: Correction of distortion by compound lens in which the negative distortion of one lens is balanced by the positive distortion of the other.

Astigmatism.—Astigmatism is one of the most serious of the aberrations and is at the same time one of the most difficult to correct. While it is not strictly accurate to say that an astigmatically corrected objective was possible only after the introduction of the newer varieties of glass following the investigations of Abbe and Schott, since Martin as well as Beck[1] have shown that anastigmatic objectives may be constructed without these glasses, the products of the Jena glass works have played an important part in the development of the anastigmatic objective, the series of barium crowns being particularly notable for having contributed largely to the rapid development in objectives of this type. The anastigmatic objective may be said to date from the introduction of the Protar by Rudolph in 1890.[2]

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[1] Martin in the Omnar produced by Emil Busch, Beck in the Neostigmar Series.

Astigmatism is an error which affects only those light pencils which pass through the lens obliquely. It is due to the lens converging the oblique pencils of light to two separate focal lines rather than a point. Astigmatism differs from spherical aberration in that the latter affects the central as well as the marginal definition, while pure astigmatism is an error found only on points removed from the axis. Spherical aberration of the oblique pencils may also exist and has already been discussed under *Coma*.

When a pencil of light falls obliquely on the surfaces of the refractive medium the course of the rays in the different planes becomes dissimilar and we must distinguish between two special planes. One of these is the plane which passes through the principal ray of the oblique pencil and is represented as the plane of the drawing. This is termed the *meridional plane*. Perpendicular to this is the *equatorial plane*.

The condition of astigmatic deformation is shown in Fig. 51.[3] The pencil of the light from the window bars at the center of the field passes along the axis and hence the image at the focal point is an exact point for point image, chromatic aberration being assumed to be absent. The pencil from the window bars on the margin of the field, however, passes through the lens obliquely and in so doing the two planes become unequally refracted and come to a focus at different points. Consequently we do not secure a perfect image of those points which lie removed from the axis but instead we have a series of image points. Thus the vertical bar comes to a focus (t) before the horizontal bar and when the former is sharp the latter is not. If the position of the ground glass is altered in the direction of s the horizontal bar is brought to a focus while the image of the vertical bar becomes less and less sharp. Hence it is impossible to secure a sharp image of both at the same time no matter in what position the ground-glass is placed. The distance between the focus of the rays in the meridional and those in the equatorial plane forms what is termed the *astigmatic difference*.

From the sectional illustration representing the appearance of the cross bar when the ground-glass occupies various positions between the astigmatic image points *t* and *s*, it will be seen that there is a point where both lines are equally sharp although *neither is critically sharp*. This point represents what is termed the *circle of least confusion.* If the image point lies near the axis, or the outstanding error is small, the diameter of the circle of least confusion may be so small as to be for all practical purposes a point image. The lens is then considered to be astigmatically corrected and is termed an *an*astigmat.

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[2] D. R. P. 56,109—April 1890.

[3] Courtesy of Dr. Hermann Kellner and the Society of Motion Picture Engineers.

Unfortunately, however, the difficulties of the designer do not end here. Generally when the astigmatic zones have been removed and astigmatic correction secured the image points lie on a curve and not on a plane perpendicular to the axis of the objective. Further calculation is then necessary in order to bring all of the astigmatic image points as close to a plane surface as possible. When this is accomplished we have what is termed an anastigmatically flattened field.

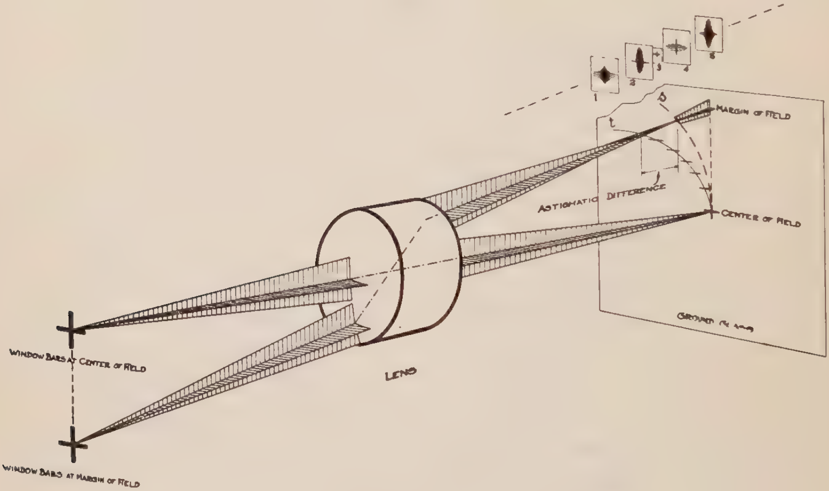

Fig. 51. Astigmatic Deformation. (Kellner)

Flare and Flare Spot.—Both flare and flare spot can hardly be termed aberrations as they are not concerned with the formation of the primary image, but as they are properties of lenses which affect the character of its image it seems well to treat them at this point.

There are two kinds of flare, one caused by reflection of light from a bright object within the lens mount and generally termed flare spot and that due to reflection of light from the surfaces of the lenses themselves. The former may be termed *mechanical flare* and the latter *optical flare.* The first can be avoided and there is little danger of flare from this source with a lens of a reputable manufacturer, unless old or damaged. Second-hand lenses should be carefully examined for unblackened spots on the mount before purchasing, while the same cause may be looked for when an old lens suddenly begins to give flat foggy images.

Optical flare cannot be avoided completely in any lens, and a lens may be excellently corrected otherwise but still useless on account of strong flare. Fig. 52 will illustrate the manner in which optical flare is produced. Let *a* and *a′* represent two parallel rays of light passing through the diaphragm and then through the lens and coming to a focus at *b*. There is a certain amount of reflection at each surface and in the case of the second surface the light is reflected back to the first surface, where it is again reflected back and reaches the plate at *c* and *c′*. If the focus of the secondary reflected image is near the same plane as the lens image, a definite spot is formed which destroys critical definition and gives a hazy, foggy effect. Any increase in the number of glasses in the objective increases the number of reflecting surfaces and hence the greater danger from flare in the more complex forms of modern lenses than in the old single achromat. In addition the deeper the curves of the individual glasses the greater the percentage of light reflected and consequently the greater the danger of flare. The presence of air spaces increases the number of reflecting surfaces so that of two lenses of the same glasses and of the same design the amount of flare will be greater theoretically in the lens in which the components are separated by air spaces.

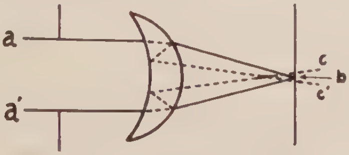

Fig. 52. Optical Flare

Some forms of modern anastigmats are more subject to flare than others and with all it is advisable to take all possible precautions to remove all sources of the same. Much can be done by the habitual use of an efficient lens hood which really ought to be regarded as an integral part of every ultra rapid objective.

Unequal Illumination.—With every collecting lens, regardless of construction, the center of the field is more strongly illuminated than the marginal portions. This falling off in intensity towards the margins of the field is known as unequal illumination, or diminution of intensity, and is due to two general causes, one of which is regular and common to every lens and the other of which varies with the lens and is dependent upon the construction of the mount.

The regular diminution in intensity is due to three distinct causes:

1. The constriction of the aperture for oblique rays.
2. The greater focal length of the marginal rays.
3. The angling of the marginal rays to the focal plane.

The manner in which the constriction of the aperture occurs is indicated in Fig. 53, where *aa* and *bb* represent the limiting rays of a direct pencil which can pass through the diaphragm *ab*. *cc* and *dd* represent an oblique pencil of light having the same diameter as *aa bb*.

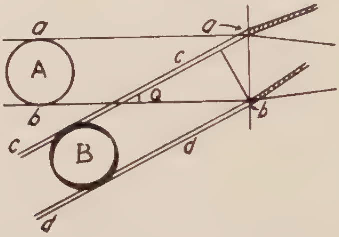

FIG. 53. Constriction of Aperture for the Marginal Pencils. (Brown)

It is easily seen that the whole of this oblique pencil *cc dd* cannot pass through the diaphragm *ab* because it meets the same at an angle and a portion of the pencil of light is cut off by the diaphragm as indicated by the shaded portions and by the sections of the aperture *A* and *B*. Therefore the effective area of the diaphragm is less for an oblique pencil than for a direct pencil and consequently the intensity of the oblique pencil after passing through the lens is less than the intensity of the direct pencil.

The second point to be considered is the fact that the focus of the oblique pencils is at a greater distance from the lens than the central pencil. This is shown in Fig. 54, where *ab* represents the distance of the focus for a central light pencil and *ac* that for an oblique pencil. It is evident that *ac* is greater than *ab*, or in other words the oblique pencils have further to travel before coming to a focus than the central pencils, which again means that their effective value is less.

Another cause of unequal illumination lies in the angling of the oblique pencil. The oblique pencil does not strike the plate perpendicularly, as do the central pencils, but at an angle. Thus in Fig. 55 the surface on which it would fall perpendicularly is *RS*, which is at the angle *cSR* to the sensitive plate *cb*. The area of each image point, represented by *ES*, becomes *cS* and the intensity from this cause is therefore less than that of the central pencils as *SE* : *cS*.

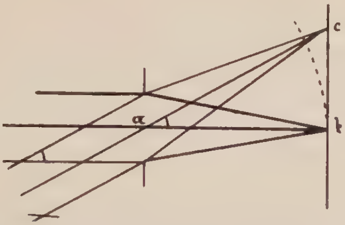

Fig. 54. Greater Focal Length of Marginal Pencils Resulting in Lower Intensity. (Brown)

The amount of the reduction in the intensity of the image at any point removed from the axis due to the above causes may be calculated mathematically provided there is no obstruction of the oblique rays by the lens mount to be considered. Formulæ for calculating the diminution in the intensity of the lens image at various distances from the axis were given by R. H. Bow as early as 1866.[4] This relation is represented in Fig. 56;[5] the angles of view subtended by the diagonal of the plate are marked along the top of the graph, while the numbers

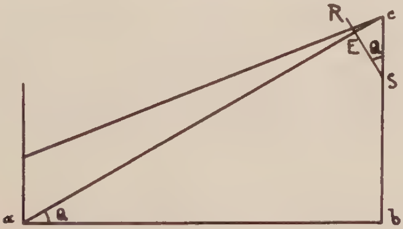

Fig. 55. The Angling of the Oblique Ray. (Brown)

below are the ratios of the diagonal of the plate to the focal length of lens corresponding to the angle of view marked on the top line above the graph. The vertical line is marked in exposures, or intensity units, starting with a unit intensity of one on the base.

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[4] *Brit. J. Phot.*, 1866, 13, 160.

[5] Zschokke, *Brit. J. Phot.*, 1917, 64, 203.

The other cause of unequal illumination lies in the obstruction of the oblique pencils by projecting lens mounts. This occurs whenever the aperture of the lens is very large in proportion to the length of the mount itself. Most modern lenses, particularly anastigmats, are very compactly built with their components close to the diaphragm and the illumination is consequently more uniform than in the case of older lenses, such as the Petzval portrait objective, which have a much larger distance between the components in proportion to the relative aperture than do modern anastigmats.

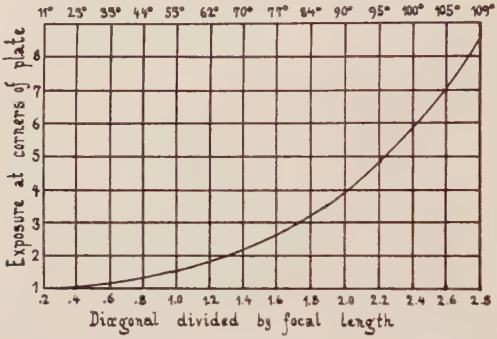

Fig. 56. Relation between the Angle of View and the Diminution of the Optical Intensity of the Image. (Zschokke)

General Reference Works

The various aberrations of photographic objectives are considered in practically all of the reference works given in the bibliography following chapter III. The following may be recommended as being especially suitable.

Harting—Optics for Photographers. (English translation by Fraprie.) 1912.
Lummer—Photographic Optics. (English translation by Thompson.) 1903.
Von Rohr—Theorie und Geschichte des Photographischen Objektivs. 1899.

CHAPTER V

THE PHOTOGRAPHIC OBJECTIVE

Introduction.—This chapter is a brief survey of the common types of lenses and the principles employed in their construction. The number of lenses which differ but slightly from a few well-established constructions is almost without number and owing to the limitations of space it is impossible to treat all of these. Accordingly the chapter will be devoted to the more important principles of construction which have been widely copied on account of their admitted excellence.

PART I. THE ASTIGMATS

Single Lenses.—It is impossible to correct a single lens in any way, hence it is unable to give sharp definition except with a very small diaphragm with the consequent sacrifice of speed. The spherical aberration is at the minimum when the lens is double convex and the radii of the surfaces are in the proportion of 1 : 6. Such a lens, however, is useless photographically because it fails to cover a flat field satisfactorily. Even with small stops the image is sharp only in the center of the field and rapidly falls off towards the margins. In 1812 Wollaston showed that a much better image could be obtained with a concavo-convex, or *meniscus,* lens than with the usual bi-convex. Wollaston's meniscus (Fig. 57) with the concave side towards the subject gives an image of satisfactory sharpness over a limited field when medium-sized stops are used. Since chromatic aberration cannot be corrected in a lens composed of a single piece of glass, the visual and chemical foci do not coincide and a correction must be made after

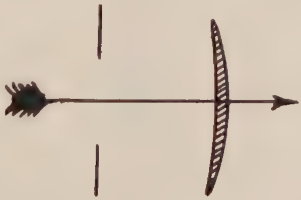

FIG. 57. Wollaston's Meniscus

focussing. The amount of this correction is equal to the focal length of the lens divided by the v constant of the glass of which it is composed. With the glass generally used for lenses of this type the difference of the two foci, or the *chromatic difference,* is equal to about 2 per cent of the focal length. The principal use of lenses of this type now is for diffused focus, impressionistic photography.

Single Achromatic Lenses.—In the preceding chapter it was shown how it is possible to correct both chromatic and spherical aberration at the same time by cementing to a single collecting lens a dispersing lens of the proper power. A lens so constructed is termed an *achromat,* or is said to be *achromatic,* i.e. chromatically corrected. Such lenses may be comparatively well corrected spherically and are able to give sharp definition over a field of medium extent when used at a maximum opening of about $F/14$ to $F/16$.

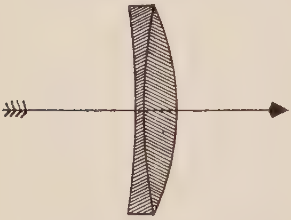

Fig. 58. The Chevalier or French Landscape Lens

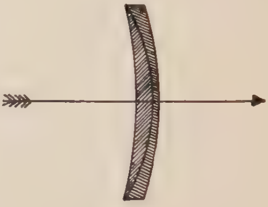

Fig. 59. Grubb's Landscape Lens

Many lenses of this type were constructed in the early days of photography. In 1857 Grubb patented an achromatic lens composed of two concavo-convex meniscus lenses cemented together, the glass nearer the diaphragm being of crown and the other of flint (Fig. 59). In 1864 Dallmeyer introduced his "Rapid Landscape Lens" which is similar to the above (Fig. 60) but differs in the introduction of a third

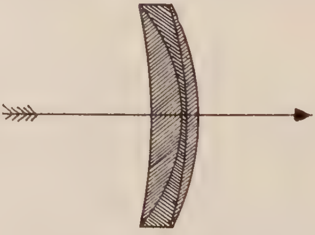

Fig. 60. Dallmeyer's Rapid Landscape Lens

meniscus of crown glass for the purpose of securing better correction.

In 1869 Goddard described a lens having the form shown in *a* of Fig. 61. For the purpose of securing better correction a convexo-concave meniscus of flint was added to the usual combination of crown and flint, an air space separating the meniscus from the double-concave negative lens. In the Dallmeyer "Rectilinear Landscape Lens" patented by Dallmeyer in 1888 the same principle is followed, the two cemented lenses being of crown glass and the separated meniscus of flint. This construction represents, perhaps, the highest attainment of a lens of this class. It has a relative aperture of $F/14$ and produces an image of satisfactory sharpness over a comparatively large field. The author has used one of these lenses for certain kinds of work for years and has found it perfectly satisfactory.

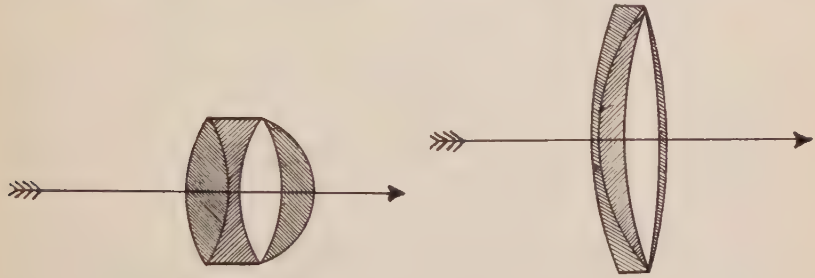

FIG. 61 (*a*). Goddard's Landscape Lens (*b*) Dallmeyer's Rectilinear Landscape Lens

Semi-achromatic Objectives or the Anachromats.—The use of partially corrected lenses at a large aperture so as to secure diffused images may be said to date from the introduction of such lenses by the French pictorialist, M. Puyo, and the construction of the Dallmeyer-Bergheim for Mr. Bergheim, a painter, in 1896.

All of the lenses within this class are only partially corrected for chromatic or for spherical aberration and to this they owe the peculiar diffusion or "enveloping image" expressed so admirably by the French word "*flou.*" The Struss *Pictorial Lens* and the *Kalosat* are concavo-convex meniscus lenses of the type represented by Wollaston's meniscus. The Smith *Semi-achromatic,* and *Synthetic,* the Spencer *Portland,* the Gundlach *Single Achromatic,* Bausch and Lomb *Plastigmat,* Degen *Objectif Anachromatique,* Hermagis *Eidoscope,* Koristka *Ars* and Dallmeyer *Soft-Focus* are all lenses resembling the single achromatic lenses previously mentioned in construction, but differing from them in the use of a much larger aperture and less thorough correction spherically. The majority of these lenses are chromatically corrected although the chromatic aberration of some is only partially carried out.

The Gundlach *Hyperion,* Wollensak *Verito* and Smith *Visual-Quality* are double lenses formed of two components which alone are essentially single achromatic lenses. In the Hyperion three foci are available as both components may be used separately. In the Verito two foci only are available as only the back component may be used alone while the components of the Smith Visual-Quality cannot be used separately. The *Dallmeyer-Bergheim* is a semi-achromatic lense constructed on the telephoto principle. It consists of a single positive and a negative lens, the space between the two being adjustable by rack and pinion. Varying the distance between the two elements alters the focal length so that the single objective is equal to a battery of lenses having a fixed focal length. The lens is not chromatically corrected and a correction must be made after focussing. The maximum aperture is $F/6.5$.

Many of the longer foci anastigmats, which are used principally for portrait work, and also some of the Petzval type portrait lenses are fitted with diffusing devices which introduce a certain amount of aberration and soften the critical sharpness of the fully corrected image.

The Double Achromat-Aplanat or Rapid Rectilinear.—The single objectives all possess, in addition to astigmatic deformation, coma, curvature of field and incomplete spherical correction, the very serious defect known as distortion. That is, straight lines cannot be reproduced as such but are rendered as parts of curves and as the diaphragm must be placed before the lens with a single objective, the distortion is barrel shaped. By constructing a symmetrical objective consisting of two achromats the diaphragm may be inserted between the two so that the barrel distortion of one element is balanced by the pincushion distortion of the other and the fault entirely corrected. In addition, owing to the superior correction which may be effected with the symmetrical construction, a larger working aperture, and consequently greater speed, is secured.

Thomas Ross appears to have been the first to make symmetrical objectives. Ross, however, does not seem to have realized the advantages of the symmetrical construction in eliminating distortion and for reducing the amount of aberration so that a larger aperture may be obtained.

In 1858, Thomas Sutton described a symmetrical triplet objective composed of a pair of single, collecting lenses with a double-concave negative lens between (Fig. 62) and in 1860 Dallmeyer introduced a lens of similar construction (Fig. 63) in which all three elements were cemented achromats. The same year Harrison and Schnitzer brought out the "globe lens" (B. P. 2496/1860). This consisted of two cemented achromatic elements and was termed the globe lens because the outer surfaces formed portions of spheres having a common center (Fig. 64). It was free from distortion but as it was not well corrected spherically it had to be used with a comparatively small stop. It was therefore soon replaced by the Aplanat and rapid rectilinear of Steinheil and Dallmeyer respectively.

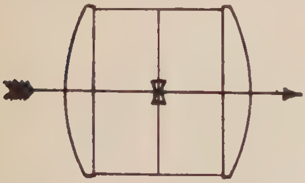

Fig. 62. Sutton's Triplet

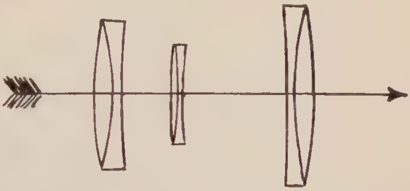

Fig. 63. Dallmeyer's Triple Achromatic

A great advance was made in 1866 when Steinheil of München introduced a symmetrical objective which he termed the Aplanat (Fig. 65). About the same time, or shortly thereafter, J. H. Dallmeyer of London independently discovered the same construction which he patented under British Patent 1641 and 2502 of 1866. Steinheil evidently reached the conclusion that astigmatism would be lessened if the refractive indices of the two glasses employed in constructing the single achromats of a symmetrical objective were more nearly equal. Therefore instead of employing flint and crown glasses, as had his predecessors, he used instead two flint glasses. Dallmeyer also used two flints.

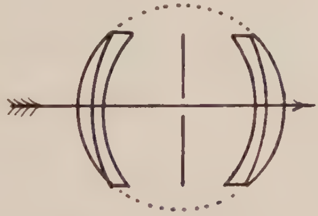

Fig. 64. Harrison and Schnitzer's Globe Lens

The first of Steinheil's Aplanats had a relative aperture of $F/8$; while an even more rapid objective designed for portrait work was patented at a later date. The Aplanat is made in several series having various speeds according to the requirements of the work for which they are intended. Roughly these series may be termed the *universal* Aplanat, the *group* Aplanat, the *portrait* Aplanat, and the *wide-angle* Aplanat.

It is the universal Aplanat with which the public is most familiar. This has an aperture of about $F/8$ and in many cases allows separate use of the components at $F/14$ to $F/16$. At these apertures the definition is satisfactory for all but the most critical work or where the results must be subsequently enlarged. The correction for chromatic aberration and distortion is very good but there is a small amount of spherical aberration, curvature of field and astigmatism remaining. However, where high speed is not required and the lens may be safely stopped down to a small opening, the rapid rectilinear is perfectly satisfactory and is an objective which does not involve a large outlay. The various makes are all made according to practically the same formula and there is no advantage in our discussing the various lenses individually.

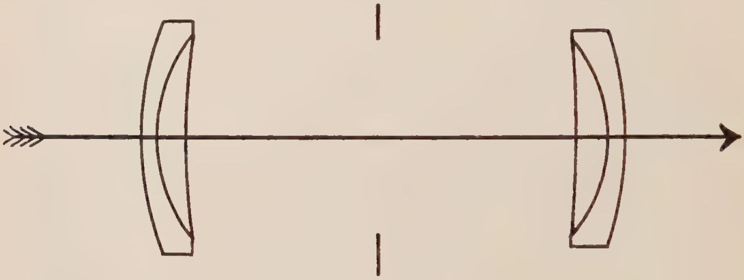

FIG. 65. The Aplanat or R. R.

Practically all wide-angle lenses which are not anastigmats are of the Aplanat construction. For this purpose curvature of field requires to be kept as low as possible while coma and spherical aberration must be highly corrected: therefore the average wide-angle aplanat has a small maximum opening, generally about $F/16$ to $F/18$.

The Petzval Portrait Lens.—The construction of the Petzval portrait lens by Voigtländer in 1840 from calculations by Joseph Petzval, a mathematician of Vienna, may be said to mark the beginning of the serious designing of photographic objectives, as well as the beginning of portrait photography. Before this time the photographer had at his disposal only the single lens with a small aperture and with the insensitive materials then available the exposures were so long that portraiture was practically out of question, except under the most favorable conditions. The Petzval portrait lens however changed all this and with its aperture of $F/6$, which was almost immediately increased to $F/4$ by Andrew Ross, portraiture for the first time became really practicable. The development of photography owes much to Petzval's achievement, for coming directly after the discovery of the daguerreotype it made that process of practical value and thus immensely increased the importance of the subject to the general public.

Joseph Petzval

FIG. 66. Portrait of Petzval

The Petzval lens consists of four lenses in two combinations (Fig. 67). The front combination consists of a positive lens of crown glass cemented to a negative lens made of flint glass, while the rear combination consists of two separate lenses, the negative lens being convexo-concave and of flint, while the positive lens is double-convex and made of crown. It is completely unsymmetrical and, because of its good correction for spherical aberration and coma, the central sharpness is excellent. It is free from distortion and is chromatically corrected. In opposition to these valuable features it has faults which limit its usefulness and have caused it to be practically replaced by the later anastigmats, except for studio portraiture. It is not astigmatically corrected, it covers a very small field, has a decided curvature of field, and owing to its length there is a considerable amount of vignetting, or a diminution of intensity towards the margins, which renders it unsuitable for landscape or other work requiring sharp definition from

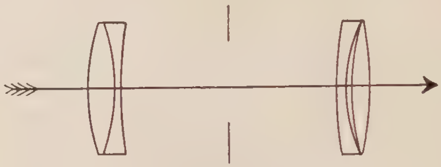

Fig. 67. Petzval's Portrait Objective

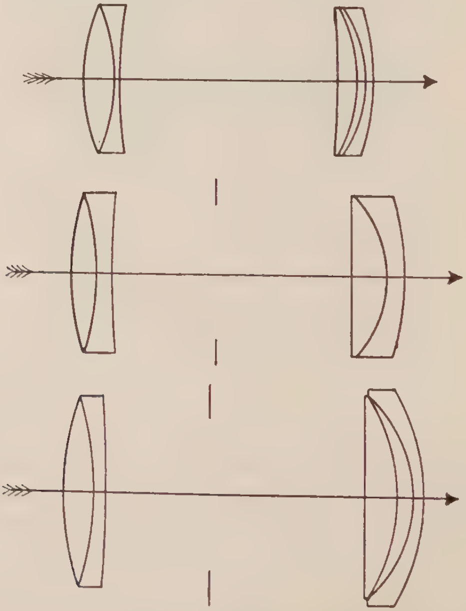

Fig. 68. Modifications of the Petzval Portrait Objective. Upper, Dallmeyer; Center, Voigtländer; Lower, Zincke-Sommer

corner to corner of the plate. Nevertheless, appearing as it did before any serious attention had been paid to the subject of photographic lens designing, it marks a most brilliant achievement—the greatest single achievement in the annals of the photographic objective.

Petzval's original construction has been several times modified by later opticians in order to improve its performance. The most important changes are those of Dallmeyer, Voigtländer and Zincke-Sommer.

In 1866 J. H. Dallmeyer modified the original Petzval design so as to obtain better spherical correction. The change consisted in reversing the glasses of the rear combination, placing the flint glass in the rear, the lens in other respects remaining practically unaltered (Fig. 68).

In 1879 (D. R. P. 5761/1879) Voigtländer changed the back combination to a plano-convex collecting lens of crown to which he cemented a concavo-convex lens of flint, the air space being removed completely (Fig. 68).

In 1870 H. Zincke-Sommer further modified the original design in order to obtain an increase in the relative aperture. The change consisted in placing the positive lens before the negative and leaving an air space between as shown in Fig. 68. The relative aperture was by this means increased to *F*/2.3.

Practically all of the modern portrait lenses, which are not anastigmatic, are constructed according to the Petzval formula, or on calculations based upon the same, and it is beyond the scope of this work to discuss the various lenses of this class now on the market and little of practical value would be gained by so doing.

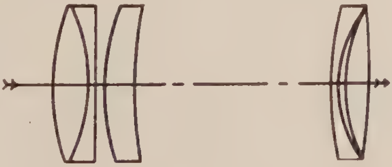

FIG. 69. Cooke F/1.5 Modification of the Petzval Construction

Lately patents have been taken out for developments of the Petzval construction for use in cinematography. One of these (B. P. 258,092 of 1925) by Warmisham is for an objective of the type illustrated in Fig. 69, and having a relative aperture of *F*/1.5.

The other patent (B. P. 299,983 of 1927) by H. W. Lee is for a combination in which the front doublet of the Petzval lens is replaced by a triplet anastigmat. The back doublet may be of the original Petzval form but better correction is secured by interchanging the two back components; i.e., placing the Petzval doublet between the dispersive element and the rear collective element of the triplet. This results in a lens of aperture *F*/1.8 with an anastigmatically flattened field of about 35 degrees.

PART II. THE ANASTIGMATS

Introduction.—Regardless of how well they may be corrected otherwise all the lenses which we have hitherto investigated contain a serious amount of astigmatism. The character, cause, and correction of astigmatism were discussed in the preceding chapter and if the matter is not clearly in mind this section of the chapter should be reviewed before proceeding.

Steinheil made one step towards the correction of astigmatism in the construction of the Aplanat but complete correction was possible only after the production of the newer varieties of glass by the Jena Glass Works. In order to correct spherical aberration in a cemented system it must have a surface convex to the medium of higher refraction, while in order to correct astigmatism the surface must be convex to the medium of lower refractive index. With the varieties of glass known before the introduction of Jena glass the refracting power increased in the same ratio as the dispersing power and it was impossible to make a spherically corrected achromat that would also be anastigmatic.

However after the introduction of Jena glass it became possible to make the collecting lens of glass having higher refraction and lower dispersion than the dispersing lens and thus secure astigmatic correction. The old achromat made of ordinary crown and flint could be corrected spherically but not astigmatically; the new achromat, however, while corrected astigmatically cannot be spherically corrected. However, by combining the ordinary crown and flint of the old achromat with the barium crown glass of the new achromat it became possible to correct both astigmatism and spherical aberration in the same lens. By combining two such achromats both of which are individually corrected to form a symmetrical objective a larger aperture becomes possible together with correction for curvature of field, coma, and distortion. This is the principle followed in the construction of most of the symmetrical lenses as the Goerz Double Anastigmat or Dagor, the Voigtländer Collinear, Turner-Reich Anastigmat, etc. The other method is to use two dissimilar combinations, one of which is spherically corrected while the other is astigmatically corrected, the two when placed on opposite sides of the diaphragm forming an unsymmetrical objective which is completely corrected as a whole but not individually. This is the principle followed in the construction of most of the high-speed anastigmats such as the Tessar, Heliar, etc.

Cemented Symmetrical Objectives.—*The Double Anastigmat.*—The Goerz Double Anastigmat, better known in this country as the *Dagor,* is a symmetrical objective consisting of two similar combinations each of which is composed of three lenses (Fig. 70). The indices of refraction of the three glasses increase as we pass from one glass to another in the direction of the incident light, i.e. from the diaphragm, as we are considering the single element. Hence the first cemented surface is convex to the medium of lower refraction satisfying the requirements for spherical correction. The second cemented surface is convex to the medium of *higher* refraction and thus satisfies the requirement for astigmatic correction. Consequently the single element of three cemented lenses is corrected both spherically and astigmatically in a very simple manner.

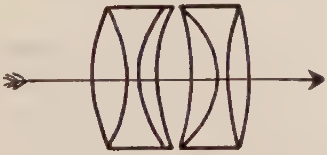

FIG. 70. The Goerz Dagor

The Dagor is excellently corrected. Its single elements do not equal the best corrected single lenses, but at an aperture of $F/13$ give a degree of definition that is satisfactory for most purposes. The relative aperture of the symmetrical objective is $F/6.8$ for the shorter foci and somewhat less for the longer. Particularly noticeable is the wide field which is critically defined at large apertures and also the extension of this field by the use of smaller stops. In this respect the Dagor is hardly to be surpassed by any other objective.

Among other lenses which are constructed according to practically the same principles may be mentioned the following:

Meyer Double Aristostigmat, *F*/6.8, *F*/5.4, *F*/4.2,
Plaubel Triple Orthar, *F*/6.8 and *F*/5.4,
Koristka Meridan, *F*/6.8,
Hermagis Aplanastigmat, *F*/6.8,
Zeiss Amatar, *F*/6.8,
Degen Double Anastigmat "Normos," *F*/6.3, *F*/7.4,
Wray Universal Anastigmat, *F*/6.8.

Alternate Form of the Double Anastigmat.—The principle embodied in the design of the Double Anastigmat just described is subject to several alterations. A second arrangement consists in the use of two negative lenses, one having a lower, the other a higher index of refraction than the interposed positive lens (Fig. 71). Here the arrangement of cemented surfaces is reversed, the indices of refraction of the three glasses decreasing as we pass away from the diaphragm. This form of the double anastigmat has been made for several years by Watson of London as the *Holostigmat* in two series, one with a maximum aperture of *F*/4.6 and the other *F*/6.1. The Steinheil *Satz-anastigmat* also has this design. Practically there is little difference in this form and the one previously described and the corrections of both may be equally well carried out.

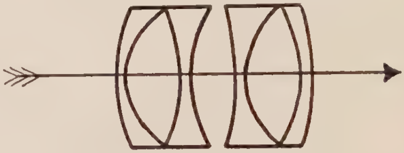

Fig. 71. Watson's Holostigmat

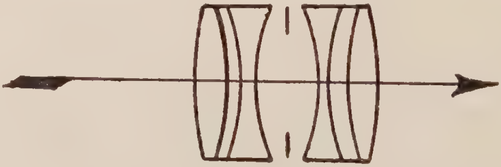

Fig. 72. The Collinear and Orthostigmat of Voigtländer and Steinheil

A further modification (Fig. 72), which was adopted in the manufacture of both the Collinear and the Steinheil Orthostigmat, consists of a meniscus of low refraction interposed between a double-convex positive lens of high refraction and a double-concave negative lens of medium refraction. If the central meniscus having low refraction is made quite thick the correction can be carried out very well so that the single elements may be used separately if stopped down. The relative aperture of the *Collinear* of Voigtländer is $F/5.6$ while the Steinheil *Orthostigmat* is made in series up to a maximum aperture of $F/6.8$.

The Four Glass Element—the Protars.—Rudolph's earlier Protars were unsymmetrical anastigmats consisting of two dissimilar combinations, one being an old achromat spherically corrected and the other a new achromat astigmatically corrected. With the exception of a series for wide-angle work these are no longer made. The series VII*a* Protar with which we are most familiar is a symmetrical anastigmat containing two like combinations each of which consists of an old and a new achromat (Fig. 73). The single element thus consists of four cemented lenses, the two nearest the diaphragm comprising the new astigmatically corrected achromat, while the other pair are similar to the old Steinheil aplanat and form the spherically corrected old achromat.

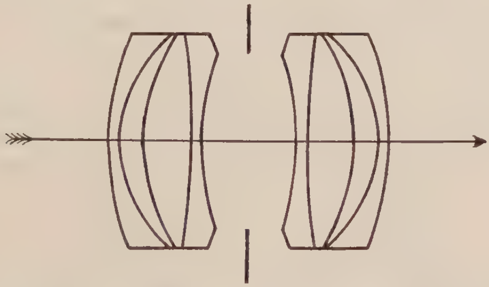

FIG. 73. Rudolph's Protar, Series VII*a*

This single element is the basis of the convertible Protar Series VII*a*. The speed of the single elements is $F/12.5$ and because of the increase in the number of glasses to four the lens is excellently corrected, its nearest competitors as regards definition being the single elements of the three glass type previously described. When a single element is used separately it should always be placed behind the diaphragm, as it is corrected for rays incident in that direction. When the complete double objective is used the element having the longer focal length should be placed in front, as the correction of the double objective depends on having the course of the light rays between the two elements parallel. In comparison with objectives formed of three-lens elements, the single element of the four-lens element is superior but the same does not necessarily hold for the double objective.

The design of the Ross *Combinable* is identical but by changes in the glasses used it has been possible to increase the aperture of the single element to $F/11$ and the double objective to $F/5.5$ without sacrificing in any way the corrections of the objective. The principal change consists in the use for the double-concave negative lens, of fluor-crown glass having very low refraction and dispersion for the boro-silicate crown glass usually used.

The Five Glass Element.—Before the introduction of the anastigmat a form of the aplanat was made consisting of three instead of two lenses for the purpose of securing better correction. When the introduction of the newer glasses made possible the construction of the new astigmatically corrected achromat Turner and Reich added the new achromat to their former three glass aplanat to form the Turner-Reich anastigmat (Fig. 74). This has an aperture of $F/6.8$ and is distinguished by the excellent correction of its single elements. Especially noticeable is the great covering power of the lens at full aperture, which is greatly increased if a smaller stop is used, and the lens may then be used as a wide-angle lens on a plate much larger than that for which it was originally designed. In this respect the Turner-Reich anastigmat is unsurpassed.

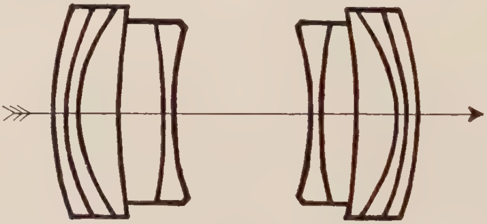

FIG. 74. The T-R Anastigmat

Symmetrical Lenses with Air Spaces—Celor and Syntor of Goerz.—In a cemented system of three lenses containing a bi-concave and a bi-convex lens with an interposed collecting meniscus of low refraction, such as the Steinheil Orthostigmat, anastigmatic flatness is secured and spherical aberration corrected by the use of two spherical cemented surfaces, one of which acts as a collecting and the other as a dispersing lens. In the Celor and Syntor of Von Hoegh (Fig. 75) the interposed collecting meniscus is replaced by an air space, so that it consists essentially of a double-convex collecting lens separated from a double-concave negative lens by an air space having the form of a positive meniscus. Corresponding to the three-lens system this two-lens system contains two contact surfaces, one of which is collecting and the other dispersive, but the contact surfaces are between air and not glass of low refraction. The two-lens system may thus be regarded as a system derived from the three-lens element by decreasing the necessary power of refraction of the enclosed meniscus until it becomes equal to the refractive index of air, or unity. Then it becomes possible to eliminate the central meniscus and replace it with an air lens, simplifying the construction and making the lens easier to manufacture.

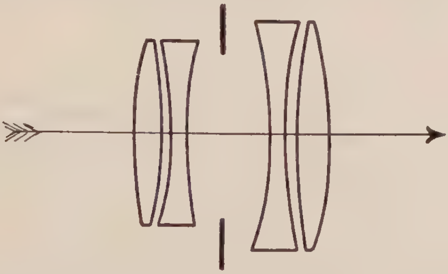

Fig. 75. The Celor and Syntor of Goerz

Lenses made according to this design were introduced by Goerz about 1900 in two series, the *Celor* having a relative aperture of $F/4.5$ and the *Syntor* with a relative aperture of $F/6.8$. The spherical and astigmatic errors of this design are small and can be practically eliminated or at least to the same degree as in the three glass element, but complete removal of coma is impossible. While coma may be entirely absent in a cemented element of three glasses, complete comatic correction is impossible for an element of two separate lenses without the loss of anastigmatic flatness of field, hence objectives of this class have a certain amount of coma which increases as the aperture is enlarged. Lately calculation has shown that better comatic correction may be secured by departing slightly from absolute symmetry in design and an objective of this type but not completely symmetrical has been introduced by Goerz as the *Dogmar* (Fig. 76). The single elements of the two-lens system can be used separately only with very small stops, as its corrections are not nearly so complete as the cemented three glass element.

A symmetrically constructed objective, each half of which is composed of four glasses arranged in pairs with a meniscus shaped air-space between them, was patented by Warmisham in 1925 (B. P. 260,801). The objective has an aperture of *F*/4.5 and gives good definition over a field of 70°. This is supplied by Taylor, Taylor and Hobson especially for aerial mapping.

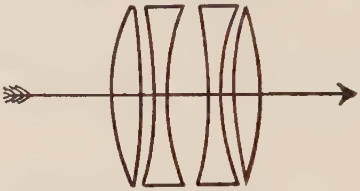

FIG. 76. The Dogmar of Goerz

The Gauss Lens.—The Gauss objective is derived from the Gauss telescope and in its simplest form consists of two menisci separated from each other by an air space and having their concave sides facing the incident light (Fig. 77). This type of construction is particularly favorable for reducing spherical aberration and may also be well corrected chromatically and astigmatically.

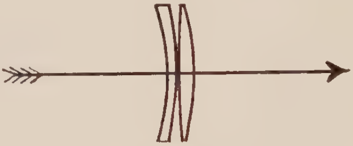

FIG. 77. The Gaussian Objective

In 1896 Paul Rudolph calculated for Carl Zeiss of Jena an objective along the lines of the Gauss construction, which was placed upon the market as the *Planar* (Fig. 78). The Planar differs from the essential form of the Gauss construction as shown in Fig. 77 by the replacement of the inner menisci by two cemented lenses. These two lenses are made of glasses having identical refractive index but different dispersions. Therefore the inner cemented lenses act as a single lens so far as the refractions of any single color are concerned, while owing to the difference in the dispersive values of the two glasses the amount of chromatic aberration may be altered simply by changing the curves of the two cemented surfaces which separate the two mediums of different dispersion. In this way the chromatic aberration of the two cemented lenses may be made to equalize the chromatic aberration of the two outer lenses so that satisfactory color correction may be obtained at the same time that the astigmatic and spherical errors are corrected. The relative aperture of the Planar is $F/3.5$, but owing to the presence of considerable coma the definition at this aperture is not critical and stopping down is necessary for critically sharp definition. The Planar is no longer made, having been replaced by the unsymmetrical anastigmats which have approximately equal speed and superior correction.

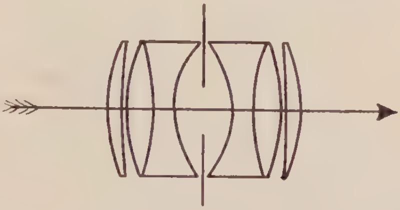

Fig. 78. Rudolph's Planar

H. Kollmorgen was the first to show that the Gaussian objective might be chromatically corrected without altering its form or affecting its astigmatic correction. Kollmorgen's method was to make each combination of an anomalous glass pair; i.e. the coefficient of refraction of the collecting lens with low dispersion must be as large or larger than the dispersing lens. A construction from calculations by Kollmorgen was placed upon the market by Hugo Meyer of Goerlitz in Germany as the *Aristostigmat*. This objective (Fig. 79) is made in several series from $F/4.5$ to $F/6.8$. The strict symmetrical construction is departed from in the larger aperture series in order to obtain better comatic correction. Especially notable is the large flat field of this objective which is a characteristic of the Gaussian construction. There is a considerable amount of coma, however, which limits the effective aperture when critical definition is required.

Identical in construction with the Meyer Aristostigmat is the Ross *Homocentric* which is made in four series: $F/5.6$, $F/6.3$, $F/6.8$ and $F/8$. The single elements of the last three series may be used alone.

The Plaubel *Double Orthar* appears to be of similar construction. It is made in two series with relative apertures of $F/6.3$ and $F/6.8$.

The *Omnar* of Emil Bush is along the same lines but the corrections were worked out in a different manner. In the Omnar the two glasses have different indices of refraction, the negative lens having the higher refracting power than the positive, while in the previously described construction both lenses have practically identical indices of refraction but varying dispersions. The Omnar can be made without the use of any of the newer varieties of Jena glass and is completely anastigmatic. The chromatic and spherical aberrations are well corrected and the objective is notable for its large flat field. Coma, however, is present as in all lenses of this construction.

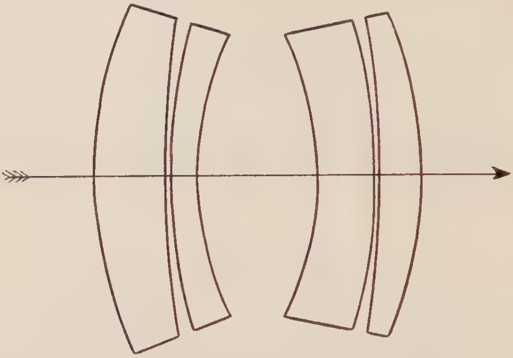

Fig. 79. Kollmorgen's Aristostigmat

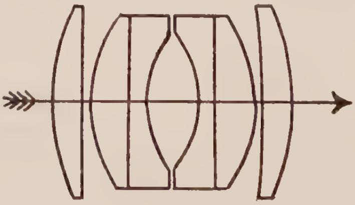

Fig. 80. Lee's T. T. H. Opic

In 1920 Taylor, Taylor and Hobson and H. W. Lee patented an improved form of the Gaussian construction which was later introduced as the Cooke Series O, *Opic* $F/2$. This objective (Fig. 80) consists of six components symmetrically arranged but not identical, two of which are simple meniscus collecting lenses of dense barium crown n_D 1.6. Between these lenses are two compound dispersive components each consisting of a plano-convex collecting lens of light flint cemented to a plano-concave dispersing lens of barium crown. The difference in the refractive indices of the two cemented lenses must be at least 0.03. The lens has an aperture of $F/2$ with an angle of view approximately equal to lenses of similar focal lengths working at $F/4.5$. Since its introduction it has been extensively employed in press photography, for theater snapshots, and other work requiring short exposures in poor light.

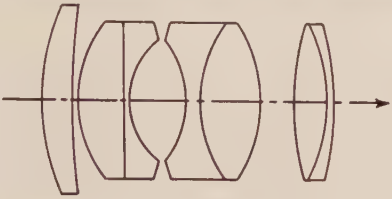

FIG. 81. Zeiss Biotar F/1.4

The Zeiss Biotar $F/1.4$ is a Gaussian type of objective which is shown in Fig. 81. The corrections compare favorably with those of the Tessar series $F/4.5$ and the lens is suitable for color work. It is made in four focal lengths: 25 and 35 millimeters for 16 millimeter cinematograph cameras and 45 and 75 millimeters for standard cinematograph cameras (B. P. 297,823 of 1927).

The Plasmat of Dr. Paul Rudolph.—In 1918 Dr. Paul Rudolph, the designer of the Planar, Unar, Tessar, Protar and numerous other objectives, calculated a symmetrical objective known as the *Plasmat* which was placed upon the market by Hugo Meyer of Goerlitz and Suter of Basel, Switzerland. The Plasmat (Fig. 82) consists of two

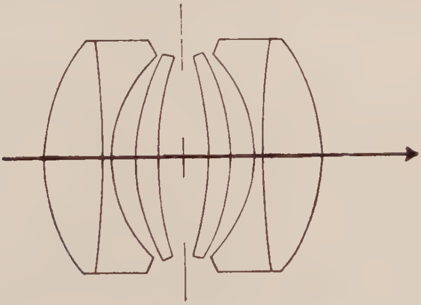

FIG. 82. Rudolph's Plasmat

similar combinations, each of which is composed of a plano-convex or convexo-concave collecting lens cemented to a double-concave dispersing lens and a thin meniscus separated from the cemented pair by an air space. The greatest curvatures are all concave to the diaphragm. The relative aperture is *F*/4 for the double lens composed of two *F*/8 elements of equal focal power and *F*/5.5 for a double objective composed of two elements of unequal focal lengths.

The original Plasmats were followed seven years later by two additional series intended especially for cinematography. These have relative apertures of *F*/2 and *F*/1.5 and are known as the Kino-Plasmats (U. S. P. 1,565,205). The construction is fundamentally the same as in the earlier series, the pair of interior dispersing meniscuses, however, are turned the opposite way from those in the earlier series. The separate components of these lenses are not designed for use separately.

In the designing of the various anastigmats which have been described, it has been the aim of the constructors to obtain the most perfect image of an object plane upon an image plane; i.e., the conditions as exist in copying. The planes before and behind this object plane vary in sharpness with their distance from the plane of sharp focus and with the aperture and focal length of the lens. The depth of field as calculated mathematically is based upon a theoretical lens free from all defects whatsoever. As no objective is perfect, the depth of focus may be less than that indicated by mathematical formulae. The more thoroughly corrected a lens, the more nearly will its representation of depth approach that of the perfect lens.

In the ordinary anastigmat the spherical correction is not equally perfect for each color. Rudolph claims to have accomplished this in the Plasmat. Owing to this superior correction of the spherical aberrations for the different colors, the Plasmat has a greater power of definition; the range of sharp reproduction covers a greater depth of image. Rudolph's claim that the Plasmat shows a greater depth of focus than other lenses of the same optical constants, has aroused a great deal of discussion in optical circles. That small differences in correction can influence depth is denied by many. Rudolph claims that his Plasmat has shown this to be true; others are yet unconvinced. Dr. Zschokke,[1] for instance, claims that the greater depth and plasticity in the rendering of the planes is due to the presence of a small amount of *uncorrected chromatic aberration.*

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[1] *Phot. Ind.*, 1921, p. 257.

Two lenses which outwardly resemble the Plasmat have been patented by Hasselkus and Richmond for Ross Ltd. of London (B. P. 295,519 of 1927) and by Carl Zeiss (B. P. 278,338 of 1926). The purpose of both of these is to provide a convertible lens of large aperture and possessing a large corrected field. The Ross Airo constructed from the above patent has an aperture of $F/4$ and covers an angular field of 70 degrees and is especially recommended for aerial map making. The Zeiss Orthometar designed for the same purpose has an aperture of $F/4.5$ and a field of 65 degrees.

Steinheil's Unofocal.—The usual method of correction for spherical, astigmatic and other aberrations is, as we have seen, the opposition of powerful lenses of different powers so as to secure compensation of the opposing kinds of aberration. In the *Unofocal* calculated by Steinheil the conditions necessary for securing an anastigmatically flat field are met with lenses of very low power free from excessive curvatures and glasses of great thicknesss, both of which react favorably on the performance of the objective.

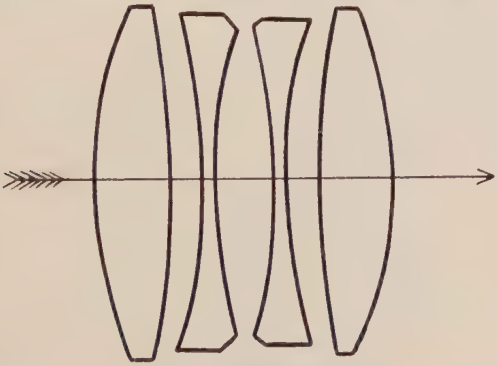

FIG. 83. Steinheil Unofocal

In the Unofocal (Fig. 83) there are two double-concave dispersing lenses interposed between two exterior collecting lenses, the general appearance of the objective closely resembling the Celor and Syntor of Goerz. The construction of the Unofocal, however, is based upon an entirely different principle and should not be considered to be in any way allied to the objectives just named. In the first place all four lenses are made of glass having practically the same refractive index and are all of the same focal power. If the lenses were placed in contact this would result in complete neutralization, so that the system would no longer have a positive focus, but by slightly separating the elements a converging system having a positive focus is secured. Spherical aberration is corrected by two refractions in the same direction assisted by the relations of the lenses and the facing surfaces. Flatness of field is made possible by the use of glass having nearly the same refractive index, while achromatism is secured by suitably balancing the dispersions of the glasses.

This design makes possible the construction of an anastigmat which owing to its shallow curves and simple construction is easily manufactured. The performance of the lens is excellent.

The Unofocal is made by Steinheil in several series, the maximum having a relative aperture of *F*/4.5.

There are several other lenses on the market which are based upon the Steinheil principle. Among those which depart but little from the original design the Gundlach anastigmat may be mentioned. This has a relative aperture of *F*/6.3.

The Graf Anastigmat and Variable.—The Steinheil Unofocal is a symmetrical lens, the two glass pairs on either side of the diaphragm being identical. In 1911 an American, Christopher Graf, designed an unsymmetrical anastigmat based upon the Steinheil design, which was introduced several years later as the Graf Anastigmat.

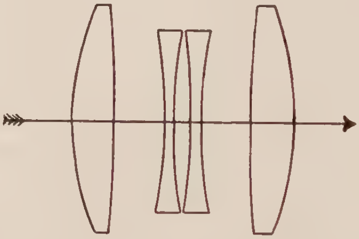

Fig. 84. Graf Anastigmat

In this objective (Fig. 84) the two inner dispersive lenses are identical with respect to each other and are symmetrically placed. The exterior collecting lenses, however, while similar are not identical either in form or position.

An especially notable feature of this construction is the most excellent quality of diffusion secured by lessening the separation between the dispersing lenses and the front collecting lens. The objective is mounted in an adjustable mount in order that the amount of diffusion may be regulated by the worker to suit the demands of the subject. The displacement of the collecting lens lengthens the focus of the system, and since the actual aperture remains unaltered, the speed consequently becomes less. The relative aperture of the objective when adjusted for full correction is *F*/3.8; when set for the maximum usable degree of diffusion, *F*/4.5.

The Beck Isostigmar and Neostigmar.—These lenses were introduced by Beck Limited of London, the former in 1906 and the latter in 1910. They differ from the lenses which we have previously described in that they do not obey the so-called "Petzval condition." According to the Petzval condition in order to secure an anastigmatic objective with a flat field the sum of the focal powers of the individual surfaces, when divided by the product of the refractive indices on either side of the surface, should be *zero*. These lenses were worked out on certain lines which do not take the Petzvel condition into consideration, so that these lenses do not obey the same.

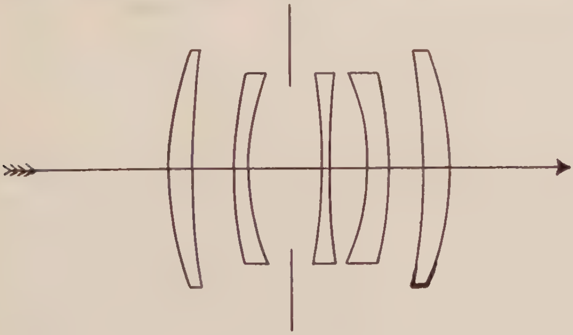

FIG. 85. Beck's Isostigmar

The *Isostigmar* is a five-lens system (Fig. 85), all of the lenses being of low power and uncemented. The two exterior are collective; the three interior dispersive. By careful calculation of the curves and the separation of the components an objective can be calculated which is very well corrected for spherical and astigmatic errors together with coma. It is made in several series with a maximum aperture of *F*/3.5 in the shorter foci and *F*/4.5 in the longer.

The *Neostigmar* is a later introduction and is simpler in construction. The single combinations are better and can be used at a larger aperture. It is a four-lens objective of unsymmetrical construction

(Fig. 86). The two exterior lenses are collecting; the interior dispersing. Convertibility is secured by removing the third or fourth lens and using the remainder of the system. The Neostigmar is made in several series with apertures of $F/6$ and $F/7.7$. One of these series is especially notable for the large field covered with satisfactory definition at $F/6.3$ and may be used as a wide-angle lens.

The Dallmeyer Stigmatic.—The opposition of a spherically corrected glass pair and an astigmatically corrected glass pair, a method adopted by Rudolph in his early Protars, suffers from the disadvantage that simultaneous correction for astigmatism and spherical aberration is impossible at a large aperture. The conditions necessary to the removal of spherical aberration *ipso facto* increase the amount of astigmatism; hence the objective cannot be well corrected for large apertures.

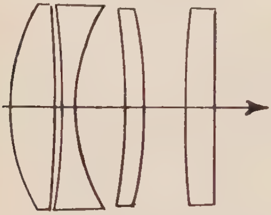

Fig. 86. Beck's Neostigmar

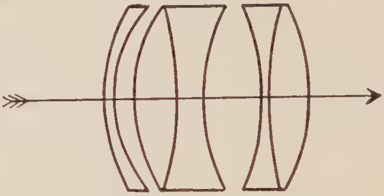

Fig. 87. Dallmeyer Stigmatic

In the *Stigmatic*, calculated for J. H. Dallmeyer by H. L. Aldis, this difficulty is overcome in a novel way. The complete objective (Fig. 87) consists of two new glass pairs to one of which has been added a strongly converging meniscus lens separated by an air space. The two cemented surfaces of the two elements formed of a new glass pair enable astigmatic correction to be obtained, while the addition of the thin, strongly converging meniscus lens enables the opposite spherical effect to be compensated for without affecting the astigmatic correction. The Stigmatic could therefore be made to work at larger apertures than the Rudolph objective. It was formerly made in several series, the largest with an aperture of $F/4$, but is now made in only one series with an aperture of $F/6$.

Rudolph's Early Protar Lens.—Earlier in this chapter we referred to the different methods adopted by Emil Von Hoegh and Paul Rudolph for the correction of astigmatism in photographic objectives. In the pages immediately preceding we traced the development of the symmetrical objective from the double objective formed by the union of two of the three glass elements as patented by Von Hoegh and Goerz in 1893. In the following pages we propose to trace the development of the unsymmetrically constructed objective from Rudolph's early *Protar* lens.

Paul Rudolph of the Carl Zeiss Werkstätte at Jena was one of the first to take advantage of the newer glasses introduced by the Jena Glass Works in the construction of photographic lenses. The first of Rudolph's anastigmatic objectives with which we are concerned was introduced in 1890 under the name *Protar*. This objective (Fig. 88) consisted of two glass pairs, one being the old normal glass pair made from the old glasses, the other the abnormal glass pair made from the newer varieties of Jena glass. One of the combinations has a *positive* astigmatic difference, i.e. the focal length of the rays in the primary section is greater than in the secondary section; while the other combination has a *negative* astigmatic difference, the focal length of the rays in the primary section being *less* than in the secondary section. By proper construction, the two opposite effects may be so balanced as to compensate one another so that there is no sensible astigmatic difference when the complete objective is said to be an *anastigmat*.

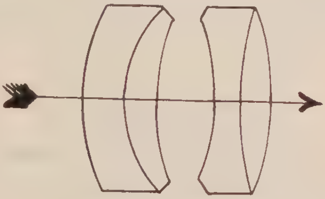

FIG. 88. Rudolph's Unsymmetrical Protar

In the normal glass pair the refractive index of the positive lens is *lower* than the adjacent negative lens, while in the abnormal glass pair the positive lens is of *higher* refractive index than the negative. Both components are separately achromatized, but are not necessarily of the same focal power, as one component may be strongly positive while the other may act simply as a corrective system for the whole. This construction because of its relatively small aperture is no longer made, except for wide-angle objectives where its extensive field makes it very suitable. The wide-angle *Protar* has this form.

The Introduction of Air Spaces—the Unar.—Some nine years after, Rudolph realized the advantages to be gained from replacing the cemented surfaces by air spaces having opposite power. This principle was applied to the construction of the *Unar* introduced by Carl Zeiss in 1899. Several forms of objectives constructed on this principle were described by Rudolph, from which that illustrated in Fig. 89 was adopted for the commercial product.

It will be observed that this objective consists of two pairs of glass surfaces, each pair consisting of two surfaces which face one another, i.e. which belong to two consecutive lenses and are separated by an air space but not by the diaphragm. The powers of both pairs of facing surfaces are of opposite sign, the first having a positive astigmatic difference, the second a negative astigmatic difference. The effect of the two pairs of facing surfaces of opposite power is similar to the result obtained in the early Protar of 1890, by the difference in the refractive indices of the crown and flint lenses in the cemented components of the doublet. Just as the two cemented surfaces, one convex to the medium of *higher* refraction, the other to that of *lower* refraction, produce opposite effects of astigmatism, so do the pairs of facing surfaces of opposite sign produce the opposite effects of astigmatism which may be completely compensated by making the two opposite effects of equal power. The introduction of the air space enables a greater degree of correction to be obtained, as the number of elements of correction are considerably increased.

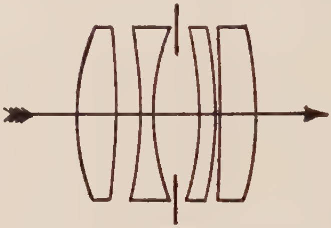

FIG. 89. Rudolph's Unar

The aperture of the Unar was $F/6$. It is no longer made, having been replaced by the Tessar introduced by Rudolph in 1902.

Combination of Air Space and Cemented Surface—the Tessar.—In 1902 Rudolph patented the objective issued by Carl Zeiss as the *Tessar*. The Tessar may be described as a combination of the early Protar and the Unar. It consists (Fig. 90) of four lenses divided into two groups which are separated by the diaphragm. The first group contains a collecting and a dispersing lens separated by an air space having a negative effect. The second group consists of a cemented negative and a positive lens, the cemented surface having a positive effect.

In the early unsymmetrical Protar lens the opposite effects by which astigmatic correction is secured are derived solely from the action of the cemented surfaces. In the Unar the said correction is based on the opposite powers of the two pairs of facing surfaces. In the Tessar these opposite astigmatic effects are obtained by giving to the power of the cemented surface the opposite sign to that presented by the facing surfaces of the other group of lenses.

The series of *F*/4.5 Tessars was followed by one having a relative aperture of *F*/3.5 and built to substantially the same formula (B. P. 273,274 of 1926) and later a series for cinematograph cameras and small cameras working at *F*/2.7 (B. P. 256,586 of 1925).

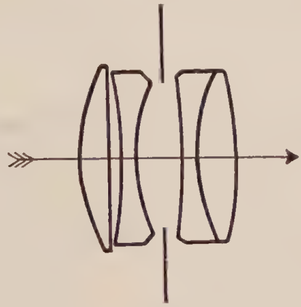

FIG. 90. Rudolph's Tessar

With the object of improving the comatic correction of the original Tessar, a modified construction was calculated by Bielicke in 1925 (U. S. P. 1,558,073); this probably forms the basis of the B. and L. Tessar Series Ic, *F*/4.5.

In 1917 as a result of calculations by Merte of the Technical staff of Carl Zeiss the spherical corrections of the original Tessar were improved and the Tessars now produced by Zeiss are probably built according to this later formula which differs from the original, however, only in the types of glass and the curvatures of the individual glasses (U. S. P. 1,476,195).

On account of its excellent corrections which place it among the best of photographic objectives, and its relatively simple construction which makes it more easily manufactured than other lenses of more complex construction, the Tessar construction has been widely copied and since the patents have expired in practically all countries there are numerous lenses by various firms which are essentially identical with the Tessar. The following lenses are of the Tessar type:

Aldis	Series I	*F*/4.5
Ernemann	Ernon	*F*/4.5
Kodak	Anastigmat	*F*/4.5
Koristka	Sideran	*F*/4.5
Krauss	Trianar	*F*/4.5
Laack	Dialytar	*F*/4.5
Plaubel	Anticoma	*F*/4.5
Rüdersdorf	Acomar	F/4.5
Salmoirach	Phoebus	*F*/4.5
Schneider	Xenar	*F*/4.5
Tiranty	Transpar	*F*/4.5
Wollensak	Velostigmat Ser. II	*F*/4.5

Combination of Air Space and Cemented Surfaces—Further Developments.—In 1912 Dallmeyer Limited patented (B. P. 27,518 of 1912) an objective on the principle of the Tessar which was introduced commercially as the *Serrac*. This objective (Fig. 91) is identical in design with the Tessar but the glasses are changed and necessarily the radii. In the Tessar the first and fourth glasses are the same, having high dispersion, while the second is of glass having a lower refractive index but higher than the third lens, which is made of glass with a medium refractive index. In the Serrac, as in the Tessar, the first and fourth lenses are of glass with a high refractive index but, unlike the Tessar, the second and third lenses are composed of identical glasses having a medium refractive index. The use of the same glasses

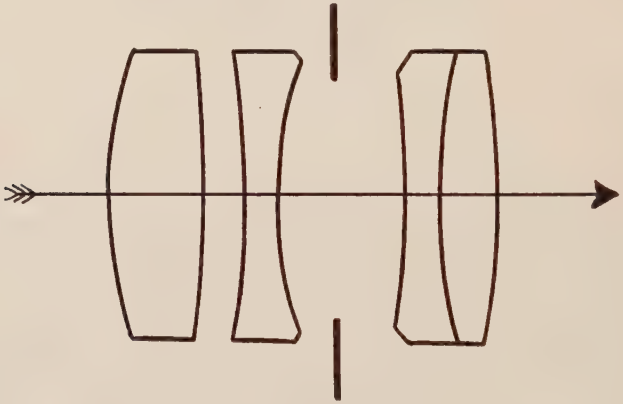

Fig. 91. Dallmeyer Serrac

for both of the dispersing lenses makes it possible to secure complete astigmatic correction with shallower radii than is possible in similar systems in which one of the lenses is composed of glass with a high refractive index and low dispersion and the other of low refraction and high dispersion and this reacts favorably on the other corrections.

The *Dalmac F*/3.5 issued by Dallmeyer Limited is a recalculation of the Serrac, only such changes having been made as were necessary to secure satisfactory performance at the larger aperture.

In 1913 Ross Limited patented the X-press (B. P. 29,637 of 1913), a lens based upon the same principle as the Zeiss Tessar but differing from it in the use of a rear element consisting of three glasses instead of two (Fig. 92). The first lens of the rear component is made of glass with low refraction, the second with medium refraction and the third with high refraction. The gradual increase in the indices of refraction together with the two cemented surfaces available enables the complete objective to be so corrected that the usual errors are at a minimum for this type of construction. Both cemented surfaces in the rear component are collective in effect.

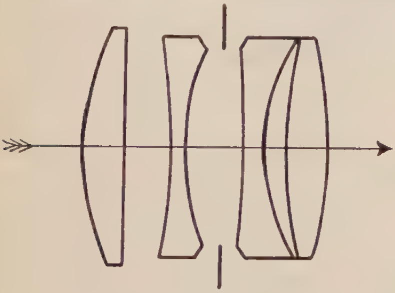

FIG. 92. Ross X-press

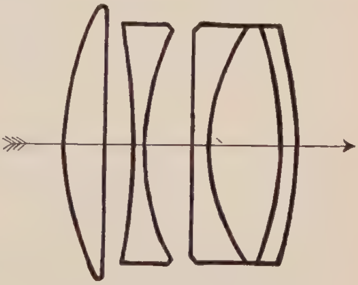

FIG. 93. Gundlach Radiar

In 1921 the Gundlach Manhattan Optical Company of Rochester, N. Y., introduced the *Radiar* (Fig. 93), a lens resembling the Ross X-press in the use of a rear element of three glasses but differing from it in that one of the cemented surfaces is collective while the other is dispersive. The three glass element was adopted because it allows a different selection of glasses and affords more latitude in balancing the powers of the component parts of the system.

The Uncemented Triplet—the Cooke Lens.—The triplet design was applied to the construction of photographic objectives at a very early date. As early as 1841, Andrew Ross made for Fox-Talbot a triplet which consisted of a concave dispersing lens of flint, interposed between two equi-convex collecting lenses of crown, and some years later Sutton worked out a similar construction, while in 1860 Dallmeyer issued his "*Triple achromatic lens*" in which each of the three components consists of a cemented collecting and dispersing lens separately corrected for chromatic aberration.

The Cooke lens patented by Mr. H. Dennis Taylor, however, cannot properly be considered as a development of the earlier triplets. Although both are triplets, the construction of the Cooke is based on a radically different principle, and the two can be said to be similar only in outward appearance. In none of the earlier triplets is the power of the negative lens more than a small fraction of the sum of the collecting lenses, and the idea of utilizing the dispersing lens for flattening the image, and correcting marginal astigmatism, apparently never occurred to these men.

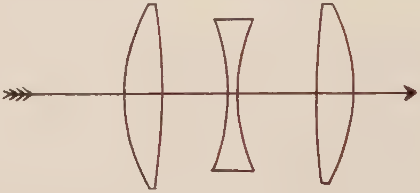

FIG. 94. Cooke Triplet

The Cooke lens is a simple triplet (Fig. 94) consisting of a double-concave dispersing lens interposed between two double-convex collecting lenses. The two collecting lenses are identical and are designed to be practically free from coma; this result being secured by the use of an intermediate form of lens in which the inward coma of one surface is neutralized by the outward coma of the opposite surface. The burden of correcting the entire system is thrown upon the central dispersing lens, which fulfills a threefold office: (1) It flattens the final image and corrects marginal astigmatism, producing a flat astigmatic field; (2) it corrects the color aberrations of the convergent lenses and makes the complete system achromatic; (3) it corrects the residual spherical aberration of the two collecting lenses and renders the final image aplanatic. The action of the negative lens in securing a flat field, free from astigmatism, may be explained with the aid of Fig. 95. *L* and *N* are respectively a positive and negative lens of equal focus and made of the same materials. With primary sections of the oblique pencils, the image formed by the positive lens, *L*, is curved spherically, *p–P*, but the interposition of the negative lens, *N*, throws back the image to the plane *Q–Q′* which is flat because the curvature errors of the positive lens, *L*, are exactly neutralized by the opposite curvature of the negative lens, *N*.

Owing to the fact that this arrangement would result in considerable distortion, and to the fact that its corrections to a certain extent depend upon the distance of the subject, the single collecting lens is divided into two which are alike in power and shape but turned in opposite directions. The positive focal power of the two converging lenses is approximately equal to the negative focal power of the central dispersing lens.

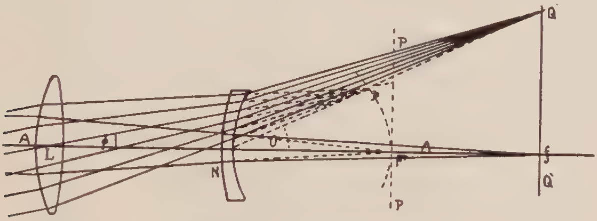

FIG. 95. Action of the Central Diverging Lens

Considering the simplicity of construction and the limited number of elements which the designer possessed to correct the usual aberrations, the Cooke lens is well corrected and at the time of its introduction (1895) surpassed the anastigmats then known in sharpness of definition over the usable angle of view. Especially notable is the almost complete absence of coma.

The Cooke triplet construction is followed by Taylor, Taylor and Hobson of Leicester, England, in the construction of several series of lenses ranging in speed from *F*/3.1 to *F*/8. The more rapid series intended for portrait work in the studio naturally are corrected for a much smaller field than those of smaller relative aperture. Owing to the simplicity of the Cooke triplet construction, its performance and to the fact that the patents have now expired, numerous manufacturers issue under various trade names objectives based upon the same principle. We mention a few:

Aldis	Series O	*F*/3
Goerz	Hypar	*F*/3.5
Rüdersdorf	(Portrait Anastigmat)	
Rodenstock	Eurynar (Older models)	*F*/4.5

Rietschel	Tular	$F/6.3$
Salmoirach	Orion	$F/4.5$
Staebel	Kaloplast,	
Steinheil	Cassar	$F/3.5$
Zeiss	Triotar	$F/3.5$

Development of the Triple Objective after H. D. Taylor—the Cooke Aviar.—In 1918 Arthur Warmisham patented a modified form of the Cooke lens which consists of four simple spaced lenses, two of which are collective and two dispersing. It is essentially a Cooke construction, the idea of a split divergent lens having occurred to Mr. H. D. Taylor in 1898, who was granted a patent for a modification of the triplet in which the central dispersing lens was developed into two similar lenses of lower individual power (B. P. 12,859 of 1898). This objective, however, had no advantages over the earlier triplet and was abandoned. By making a special study of coma, Warmisham was able to develop an objective of this type which has a larger flat field than the triplet.

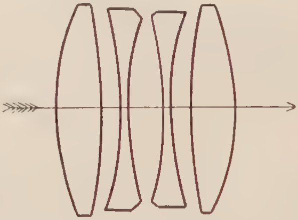

Fig. 96. Cooke Aviar

The original Aviar as used extensively by the Royal Air Force in the latter years of the World War called for the use of a highly refractive baryta crown glass for the front collecting lens. This glass, however, is not very stable and discolors on prolonged exposure to the atmosphere. Accordingly in 1928 Warmisham recalculated the formula to permit the use of a more stable baryta crown without affecting the degree of correction (B. P. 312,536 of 1928).

Development of the Triplet Objective after H. D. Taylor—the Aldis Lens.—Three objectives of this firm demand attention. Series II*a* $F/6.3$ (Fig. 97) may be regarded as a development of the triplet construction of H. Dennis Taylor as described in British Patent No. 1699 of 1899. The central dispersing lens is separated from the front collecting lens by a small air space having a positive effect. The rear collective lens is separated from the front element by the diaphragm.

In the original Cooke triplet the collecting lenses are approximately equal in focal power, here the front collecting lens is much more powerful than the rear.

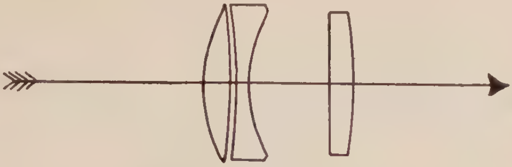

FIG. 97. Aldis Series II*a*

Series II and Series III may also be considered as having been evolved from the Cooke triplet, although they fall into entirely different classes. In both of these (Fig. 98) the front collecting lens is cemented to the central dispersing lens while the rear collecting lens of low power is placed some distance from the cemented element. Series II has a relative aperture of *F*/6; Series III of *F*/7.7.

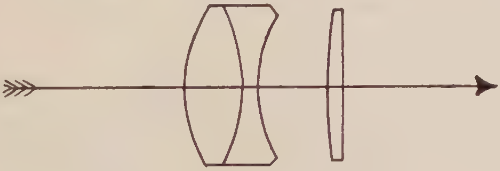

FIG. 98. Aldis Series II and III

Triplets with a Pair of Collecting Cemented Surfaces—the Heliar.—In 1900 Hans Harting calculated for Voigtländer an objective which is essentially a development of the simple triplet of H. Dennis Taylor, which was introduced commercially as the *Heliar*.

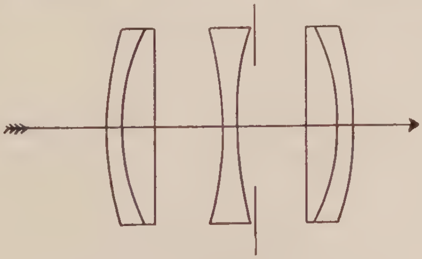

FIG. 99. Harting's Heliar

In the Heliar (Fig. 99) the triplet construction is plainly evident from the general similarity of the design. The development made by Harting consists in replacing the single collecting lens of the original triplet of H. Dennis Taylor by a cemented element of two glasses. By increasing the number of elements of construction and the introduction of cemented surfaces the initial errors of construction are lessened and excessive curvatures avoided so that the corrections are more easily and fully carried out, resulting in better field covering at a large aperture. The aperture of the Heliar is *F*/4.5 in all sizes and the area of the field covered with satisfactory sharpness is greater than that of the simple triplet.

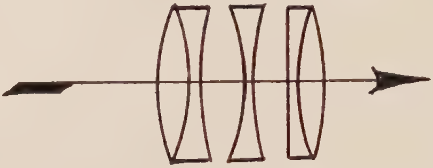

FIG. 100. Harting's Dynar

The Dynar.—Two years later Harting calculated for Voigtländer a similar construction but with the glasses of the cemented components reversed in position so that all three dispersing lenses are placed together. This construction was introduced as the *Dynar* (Fig. 100); and was made principally for hand cameras and has a maximum aperture of *F*/6.

The Pentac.—While the *Pentac* issued by J. H. Dallmeyer from calculations by Lionel Barton Booth is described in British Patent Specification No. 151,506 as a development of the Tessar, the single collecting lens of the former being replaced by a cemented component consisting of a collecting and dispersing lens with collecting cemented surface, examination shows that the Pentac has more in common with the Heliar and particularly the Dynar than with the Tessar (Fig.

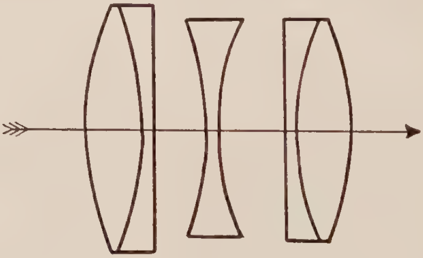

FIG. 101. Dallmeyer's Pentac

101). Both the Dynar and the Pentac are five-lens systems consisting of a double-concave negative lens interposed between two collecting elements formed of a cemented collecting and dispersing lens and both the exterior lens and the cemented surface are collective in effect.

By rigid calculation an objective has been calculated which has an unusually large aperture of *F*/2.9 and can be well corrected up to a focal length of 12 inches.

The Ernostar.—This objective of Ernemann of Dresden is based upon the Cooke triplet. The front collecting (Fig. 102) lens of the latter, however, has been replaced in the new objective by two elements, each composed of two cemented lenses, the front lens of each pair being collective and the rear lens dispersive in effect. The two elements are separated from one another by an air space having a dispersive effect. The action of this complex front component is to secure greater convergence of the incident rays so that the path of the ray after passing through the central negative component may be either converging or parallel and not diverging as in the original triplet of H. Dennis Taylor. The division of the front member into two separate components increases the number of elements at the disposal of the calculator, since there are four glasses and an air space, and this has enabled the corrections to be carried to a high degree of perfection notwithstanding its large relative aperture of *F*/2. The spherical aberrations, astigmatism and zonal errors are almost completely removed and the field is flat and free from distortion. So completely has the chromatic correction been carried out that the objective may be considered to be sphero-achromatized and apochromatic.[2]

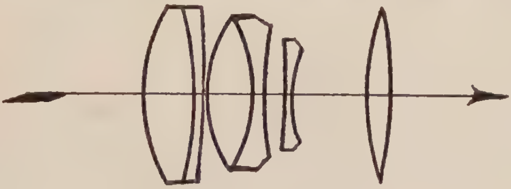

FIG. 102. The Ernostar

A more simple construction for a triplet with a relative aperture of *F*/1.8 has been patented by Warmisham (B. P. 280,392 of 1926).

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[2] British Patents 186,917/1921, 191,702/1922, 193,376/1922, 232,531/1924. Klughardt, *Phot. Ind.*, 1924, p. 1008.

The first collecting member and the central diverging member are both cemented doublets, while the rear collecting member is a simple collecting lens. Thus, there is secured a 6 glass-to-air surface lens with an aperture of $F/1.8$.

PART III. THE TELEOBJECTIVE

Principle of the Teleobjective.—If we take two lenses made of the same glass and having equal but opposite powers, one being negative and the other positive, it is evident that if they are placed in contact with one another the converging power of the positive lens will be exactly balanced by the dispersing power of the negative lens and there will be no alteration in the direction of the incident ray. The combination thus neutralized has no real focus, or it may be said to have infinite focal length. However, if we separate the positive and negative lenses the focal length will gradually shorten until finally we reach the *zero position* where the focal distance is equal to the focal length of the positive lens, the negative lens then being without effect on the focus. The negative lens may thus be said to take a portion of the image produced by the positive lens and magnify it. The amount of the magnification depends upon the focal length of the objective which in the teleobjective is determined by the distance between the positive and the negative lenses. This distance between the lenses, or Δ, increases as the focal length decreases and *vice versa*.

The separation of the two lenses also brings about another change. When the two are in contact the principal point coincides with the common lens vertex, but as the components are separated the principal point moves away from the lens in the direction of the subject. Since the focal length is the distance from the principal point to the point of intersection of the convergent rays, the distance from the focal plane, or the ground-glass, to the lens is less than the equivalent focal length. Hence we are able to make use of a long focus objective without a bellows extension of corresponding length. This is the principal point of value of the teleobjective.

The Compound Telephoto Objective.—The earliest use of a negative lens in the above described manner is found in the Galilean telescope. Its first use for photographic purposes is credited by Harting to J. Porro in 1851.[3] The matter, however, remained unnoticed by the optical world at large until the latter part of the nineteenth century when it was independently invented by several opticians and is now made by nearly all manufacturers of photographic lenses.

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[3] *Optics for Photographers*, English translation, p. 185.

As a typical example of the compound teleobjective we may mention the design patented by Dallmeyer in his English patent No. 21,933 of 1891. The positive component of this system is the well-known Petzval portrait lens; the posterior negative element is a symmetrical double combination as illustrated in Fig. 103 and is chromatically and spherically corrected. The two elements are mounted in a tube fitted with an adjustable screw by which the separation of the positive and negative components may be altered to secure any desired degree of magnification.

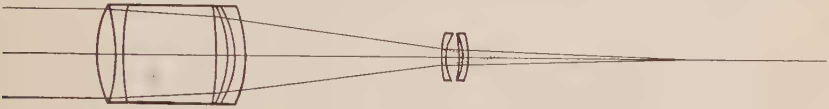


FIG. 103. Dallmeyer's Compound Teleobjective

Most manufacturers are in a position to fit, to such of their objectives as may be suitable, a negative combination similar in general construction to the above. When ordering the negative lens the objective to be used as the telepositive should be sent to the manufacturer in order that the two may be properly adjusted.

The advantages of variable focal length and size of image together with short bellows extension are important features and if it was not for the serious disadvantage of lack of speed, which considerably limits its usefulness, the compound teleobjective would be widely used. It is not difficult to understand the reason for the lack of speed when we consider the principle upon which the teleobjective is based. The image formed by the positive lens is enlarged (spread over a larger area) by the negative lens; therefore the intensity of the image is less and a longer exposure is required. The higher the degree of magnification the greater the exposure required. Mathematically the aperture of a teleobjective may be expressed as

$$\frac{D}{f_1}\Big/\frac{f_2}{\Delta},$$

where D is the aperture of the positive objective,

f_1 the focal length of the positive lens,
f_2 the focal length of the negative lens, and
Δ the separation of the positive and negative lenses.

Furthermore some stopping down of the positive lens is nearly always necessary in order that the aberrations of the negative lens (which cannot be completely corrected because the distance between the two elements is subject to considerable variation according to the requirements of the subject) do not unduly interfere with the central definition. This still further lengthens the time of exposure so that hand camera work and the photography of moving objects becomes possible only in very exceptional cases. For this reason the compound teleobjective is of value only for a limited type of work and has been almost completely replaced by the modern fixed-magnification, high-speed, anastigmatic teleobjective.

Early Fixed-Magnification Teleobjectives.—While it is impossible to secure a very large aperture with the compound teleobjective, if we fix once for all the separation of the positive and negative elements so that we secure a fixed degree of magnification we are enabled to considerably increase the working speed of the combination and without any loss of definition. Strictly speaking, the first fixed-magnification teleobjective was the *Orthoscopic* lens worked out by Petzval and introduced commercially by Dietzler in 1856. This objective (Fig. 104) consists of a front positive combination similar to that of the regular Petzval portrait lens and a back negative combination with a bi-concave and concavo-convex lens, the two being chromatically corrected so that the objective consists essentially of

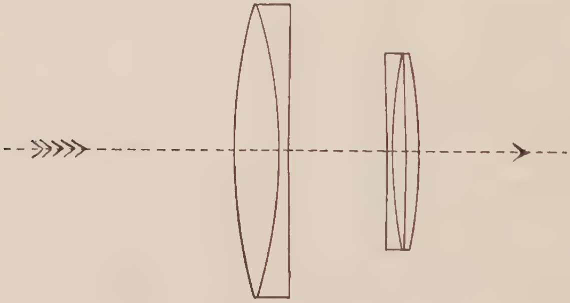


Fig. 104. Petzval's Orthoskop

two achromats, one of which is collecting and the other dispersing. This rear component magnifies the image in just the same way as in the compound teleobjective but as the usual corrections have to be made for only one degree of magnification, and not an entire series as in the other case, it becomes possible to give to the whole objective an aperture considerably in excess of that which is possible with the compound teleobjective.

The possibilities of the Orthoscopic construction were not realized at that time, however, and with the advent of the aplanat it ceased to be made. It was not until 1905 that the first of the modern fixed-focus teleobjectives was introduced, the *Bis-Telar* of Emil Busch. This was designed by K. Martin and was composed of two cemented doublets (Fig. 105) and had a relative aperture of *F*/9 and a magnification-ratio of 1⅔. Soon afterwards Zeiss brought out the *Magnar* (Fig. 106). This was calculated by Rudolph and Wandersleb and had a magnification-ratio of 3 times with an aperture of *F*/10. The positive component was a doublet and the rear a triplet.

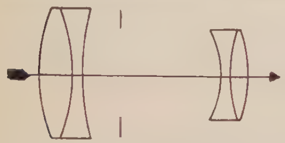


FIG. 105. Martin's Bis-Telar

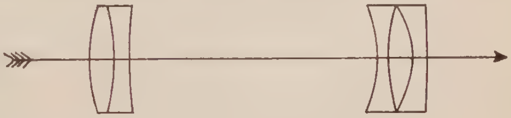


FIG. 106. Zeiss Magnar

The Anastigmatic, Fixed-Focus Teleobjective.—Designers then began to turn their attention towards the more complete astigmatic correction of the teleobjective. In 1912 Ross Limited issued from the calculations of Stuart and Hasselkus the *Telecentric*, a fixed-focus teleobjective, the positive component of which was a cemented triplet and the rear component a cemented doublet (Fig. 107). This was

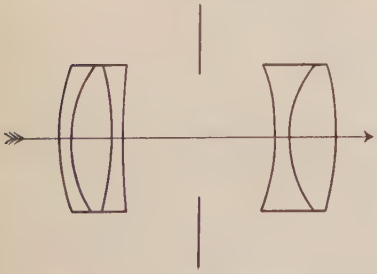


FIG. 107. Ross Telecentric

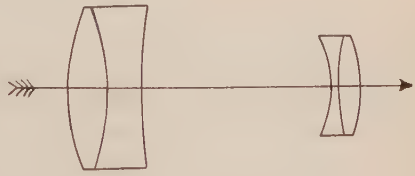


FIG. 108. Dallmeyer Large Adon

issued in two series, one working at F/5.4 and the other at F/6.8. Two years later Lan-Davis patented (B. P. 1185 of 1914) an anastigmatic teleobjective which was introduced by J. H. Dallmeyer Limited as the *Large Adon.* This objective (Fig. 108) consists of a positive component containing a cemented collecting and dispersing lens forming an achromatic pair but with considerable remaining spherical aberration. The rear dispersing component consists of either two or three cemented lenses which form an achromatic combination and are so corrected spherically as to compensate for the spherical aberration of the front member. In this way a comparatively well-corrected objective with an aperture of F/4.5 was obtained.

The same year Lionel Barton Booth calculated and patented (B. P. 3096 of 1914) a four-lens construction in which the members of the positive element were separated by an air space. This had a relative aperture of F/5.8 and was a notable improvement over earlier objectives of this class as regards definition and was made by Taylor, Taylor and Hobson in considerable quantities for the use of the British Air Force during the World War.

From the standpoint of the manufacturing optician it was desirable to eliminate, if possible, the air space between the two members of the positive element. This problem was solved by Booth, who in 1920 took out two patents (B. P. 139,719 and 151,507) for fixed-focus, anastigmatic teleobjectives, each element of which consists of a cemented doublet (Fig. 109). This construction was introduced by J. H. Dallmeyer Limited in several series as the *Dallon.* Series VI, XVI and XVIII have a magnification of 2 times and relative apertures of F/5.6, F/7.7 and F/6.5 respectively. Series XVII has a relative aperture of F/6.8 and a magnification of 2½ times.

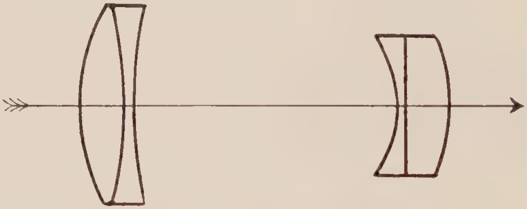


Fig. 109. Booth Teleobjective

A similar construction was patented by H. W. Lee (B. P. 198,958) and introduced by Taylor, Taylor and Hobson as the *Cooke Telic.*

This has a relative aperture of $F/5.5$ and a magnification-ratio of 2 times.

The *Radiar* telephoto anastigmat (Fig. 110) introduced by the Gundlach-Manhattan Optical Company is of similar construction.

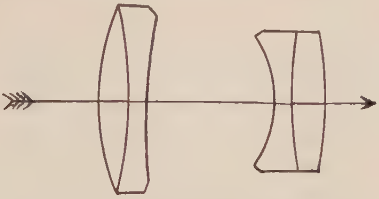


Fig. 110. Radiar Teleobjective

The positive member consists of a cemented doublet with a front collecting lens of barium crown and a dispersing lens of heavy flint, while the rear member consists of an inner dispersive lens of barium crown and an outer collecting lens of light flint.

The telephoto lenses already described show a small amount of distortion which, for general purposes, is not of serious importance. A non-distorting telephoto as constructed by Taylor, Taylor and Hobson, has the form shown in Fig. 111 (B. P. 222,709 of 1924). The "barrel-shaped" distortion produced by separating the two elements of the rear dispersive member is neutralized by the opposite type of distortion introduced in the front member by the addition of a collecting meniscus, thus resulting in orthoscopy. The Cooke Telekinic $F/3.3$ has this form.

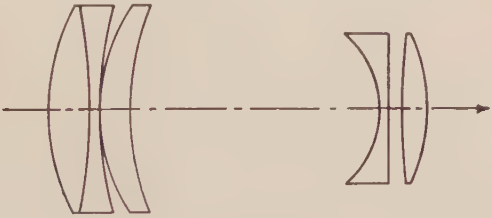


Fig. 111. Cooke Telekinic $F/3.5$

In the *Tele-tessar* of Zeiss the rear component is composed of two cemented meniscii the positive member is placed nearest the diaphragm and not on the exterior as in the case of the Dallmeyer Dallons and the Cooke Telic (Fig. 112). The Tele-tessar has a relative aperture of $F/5.5$ and a magnification-ratio of 2 times.

In order to construct a fixed-magnification teleobjective with a magnification above two and maintain an anastigmatically flat field at the same time it becomes necessary to increase the number of elements. In the *Teleros* introduced by Ross Limited from calculations by Stuart and Hasselkus the rear component is a cemented triplet in which two negative lenses enclose a positive member of glass having lower refraction and higher dispersion (Fig. 113). The objective has a relative aperture of *F*/5.5 and a magnification-ratio of slightly over two times. H. W. Lee has also patented a fixed-focus teleobjective (Fig. 114) in which the rear component is a triplet with a positive lens of low refraction between two negative members of high dispersion. This is manufactured by Taylor, Taylor and Hobson and has a relative aperture of *F*/5.5 and a magnification-ratio of 3.

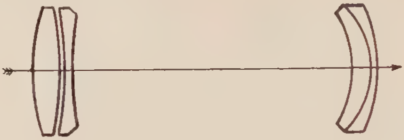


FIG. 112. Zeiss Tele-tessaar

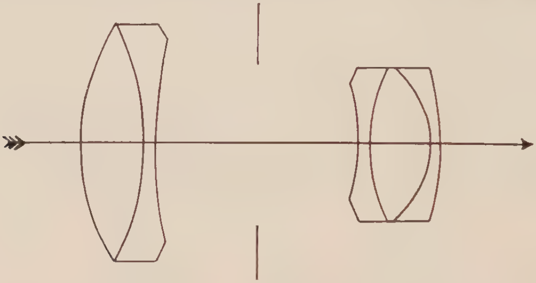


FIG. 113. Ross Teleros

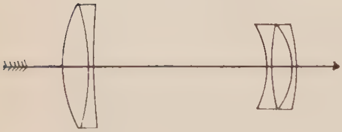


FIG. 114. Lee's T. T. H. Telephoto

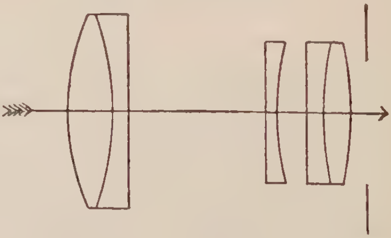


FIG. 115. Voigtländer's Tele-Dynar

The *Tele-Dynar* of Voigtländer also has a rear element of three members, two of which are cemented and the other separated by an air space (Fig. 115). Several other manufacturers have departed from the simpler constructions already described, but as they are for the most part unknown in this country we do not propose to discuss them further.

The Adon.—Before leaving the subject of the teleobjective mention should be made of a construction invented by Dallmeyer and utilized in the construction of the *Adon.*

If the positive and negative elements of a tele-compound are separated by a difference equal to the difference of their focal lengths, incident parallel rays emerge parallel and an ordinary objective focussed for parallel rays when applied to the rear of this combination will form an image at the focal plane of the ordinary objective, the magnification of the image depending upon the ratio of the focal lengths of the positive and negative lenses (Fig. 116). To maintain the actual F value of the photographic objective for any degree of

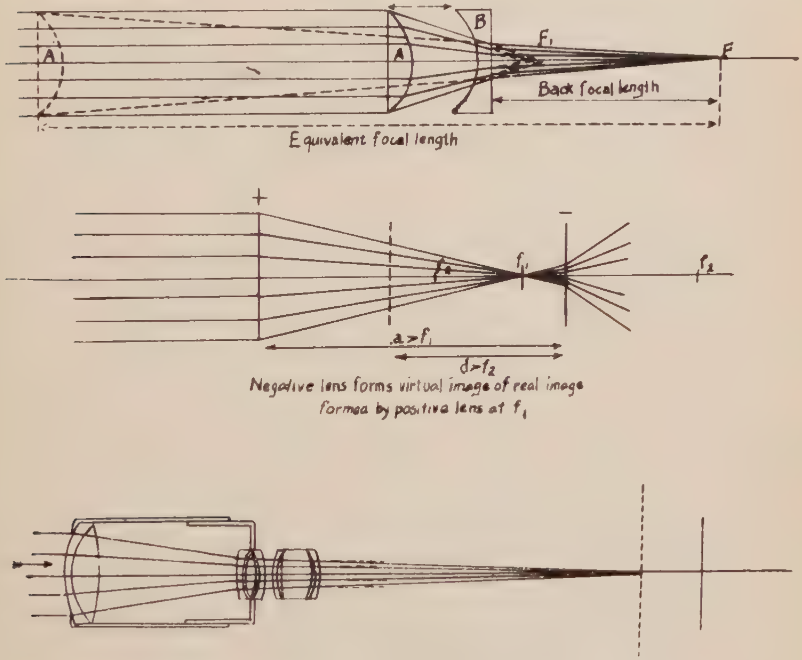

A
A
B
F1
F
Back focal length
Equivalent focal length
+
−
f0
f1
f2
a>f1
d>f2
Negative lens forms virtual image of real image formed by positive lens at f1

Fig. 116. Dallmeyer's Adon

magnification the parallel pencil emerging from the magnifying system must be as large as the aperture of the objective to which it is applied, therefore the exterior positive element of the enlarging system must be as many times greater in diameter as the lineal degree of magnification desired. Thus we work without loss of speed, the effective aperture being the same as that of the objective alone. This principle, however, can only be used with objectives of moderate diameter and for low degrees of magnification.

General Reference Works

Eder—Die Photographischen Objectiv.
Fabre—Encyclopedique de Photographie.
Gleichen—Lehrbuch der Geometrischen Optik.
Gleichen—Theorie der Modernen Optischen Instrumente. (The English translation by McElwain and Swan contains a table of modern objectives which is not found in the original German edition.)
Harting—Optics for Photographers. (English translation by Fraprie.)
Lummer—Contributions to Photographic Optics. (The English translation by Thompson contains two chapters on British objectives which are not found in the original.)
Puyo and Pulligny—Les Objectifs Anachromatiques.
Turriere—L'Optique Industrielle. 1920. (The most complete work on the later anastigmats.)
Von Rohr—Theorie und Geschichte der Photographischen Objektiv.

CHAPTER VI

THE PHOTOGRAPHIC EMULSION

Introduction.—Properly speaking, the use of emulsions in photography dates from the publication of the first practical method of preparing collodio-bromide emulsion by Sayce and Bolton in September 1864 but it is in connection with gelatine that the term emulsion is generally associated. The gelatine emulsion which has played such an important part in the development of photography dates from the investigations of an English amateur, Dr. Richard Leach Maddox, whose paper describing the preparation of a sensitive gelatine emulsion was published in the *British Journal of Photography* for September 8, 1871. His method, however, was not a practical one and gelatine emulsion on a basis similar to that now in use did not appear until several years later. Although a gelatine emulsion had been placed upon the market as early as 1873 by Richard Kennett, gelatino-bromide emulsion of practical utility may be said to have first appeared in 1878 after the discovery of the great increase in sensitiveness to be secured by the application of heat to the finished emulsion. In the meantime three very important points had been cleared up. King and Johnson had shown the necessity for the removal of the soluble salts from the emulsion and indicated means of effecting this; the last named worker had also shown the importance of using an excess of soluble bromide rather than an excess of silver salt; while Bolton had suggested that the emulsion be formed in a small amount of gelatine and the remainder added at a later stage—a method which became very valuable after the discovery of digestion processes with heat.

As is fairly well known, the gelatine emulsion which forms the sensitive coating of our plates and films consists primarily of a highly sensitive form of silver bromide and gelatine. If silver bromide is formed in aqueous solution by the double decomposition of a soluble bromide, as potassium bromide, and silver nitrate and the nitrate allowed to stand a short while, the silver halide will begin to precipitate upon the sides and bottom of the vessel. However, if the silver bromide is formed in the presence of an aqueous solution of gelatine instead of water the solution is at first clear and slightly opalescent and on standing becomes milky or creamy. .On standing the silver halide does not precipitate out of solution, as in the case of water, but remains in a homogeneous state. This mixture of finely divided silver halide and gelatine is termed gelatino-bromide *emulsion.* It is not really an emulsion, however, in the sense in which that term is used in colloid chemistry, but a solution of gelatine carrying in suspension minute crystals of solid silver halide. In its simplest form an emulsion may consist purely of silver bromide and gelatine, but at times a small percentage of another halide, chiefly the iodide, but sometimes the chloride, may be added. The available evidence at the present time indicates that in such cases the silver iodide, or chloride as the case may be, is held atomically dispersed within the silver bromide and neither combine schematically with the latter nor exists separately as individual crystals. The processes of emulsion making are therefore concerned with the formation of a uniform, homogeneous suspension of a sensitive form of silver bromide in a solution of gelatine.

Gelatine.—Gelatine belongs to that class of substances known as *colloids* from the Greek κόλλα meaning glue. The substances of this class were termed colloids by a Glasgow chemist, Graham, who found that certain substances in solution such as albumen, glue and gelatine do not pass through an animal membrane, while solutions of crystalline substances such as common salt do. To the former class of substances Graham applied the term *colloids;* to the latter class *crystalloids.* In colloidal solutions the subdivision of the particles is not so high as in the case of the crystalloids and it is for this reason that they do not pass through filter materials and membranes. Two other terms, *sol* and *gel,* were also introduced by Graham. To the liquid solution of a colloid he applied the term sol; to the jelly the term gel.

The value of gelatine for photographic emulsions is due to its unique physical properties as well as its chemical composition. The easy reversibility of the transition from the sol to the gel and *vice versa,* or

$$\text{Hydrosol} \rightleftharpoons \text{Hydrogel},$$

is of paramount importance for photographic purposes and it is in this respect that gelatine is distinctly superior to any other colloid.

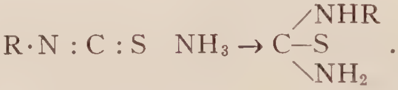
Gelatine swells in cold water but does not dissolve. Hot water dissolves it, but on cooling it again forms a jelly even if the concentration of the solution is as low as 1 per cent. The formation of the jelly from the sol is termed *setting* and the reverse reaction *melting* and the temperatures at which the change of state takes place as *setting points* and *melting points.* Technical gelatines are broadly classified as hard, medium and soft. A hard gelatine solidifies quickly and becomes quite hard, offering considerable resistance to reswelling. A soft gelatine is exactly opposite in character, solidifying slowly and reswelling quite easily. For emulsion's a hard gelatine is easier to work, especially in summer or in hot climates, as the emulsion adheres to the support better and does not soften unduly in development. Hard gelatine, however, develops slowly, owing to the fact that the penetration of the film by the developing solution is more difficult. Accordingly, in practice the emulsion maker uses a medium gelatine, combining hard and soft gelatines in the proportions which his experience has taught him to be the best for general purposes.

Aside from acting as an emulsifying medium, gelatine acts as a protective colloid. If silver bromide is formed by the combination of solutions of silver nitrate and potassium bromide, using a slight excess of the latter, and the precipitated silver bromide washed to remove all traces of extraneous salts it will be found that on the application of a developer the silver bromide will be immediately reduced whether exposed to light or not. Sheppard and Mees attribute the protective action of gelatine to the insulation of the nuclei of the silver bromide grain with which effect is associated a delay in the aggregation of the silver amicrons to form larger nuclei.[1]

Authorities have largely been at a loss to account satisfactorily for the fact that emulsions of much higher speed may be prepared with gelatine than with any other colloid. The earlier conception of the value of gelatine being due to its functioning as a photochemical sensitizer by absorption of halogen has largely been abandoned. Until only a few years ago it was a disputed point as to whether gelatine should be regarded as being directly responsible for the high sensitiveness of our modern sensitive materials or whether it acted merely as a passive medium facilitating the growth of the most sensitive form of the silver halide grain. Another disturbing factor was the

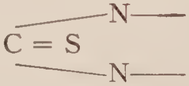
[1] For an interesting discussion of this subject see "Note on the Function of Gelatine in Development," by Dr. T. Slater Price. *Phot. J.*, 1925, 65, 94.

action of various gelatines on emulsion sensitiveness. From the earliest days of gelatino-bromide emulsion it had been known that emulsions prepared in precisely the same manner but with different samples of gelatine might vary greatly in light sensitiveness. After methods of determining the size-frequency distribution of grains of silver halide in emulsions had been evolved it was possible to show that emulsions having the same physical characteristics as regards size of grain and size-distribution of grains might vary considerably in light sensitiveness. A long series of investigations in the Eastman Research Laboratory brought to light the existence of what is termed Gelatine-X, the presence of which in ordinary gelatine is largely responsible for photographic sensitiveness. This Gelatine-X has been found to be analogous to allyl mustard oil and to be an allyl isothiocyanate ($C_3H_5 \cdot NCS$) which reacts readily with ammonia to produce a thiocarbamide, e.g.



$$R\cdot N : C : S \quad NH_3 \rightarrow C{-}S \begin{array}{l} \diagup NHR \\ \\ \diagdown NH_2 \end{array} .$$

Experiments show that the group



$$C = S \begin{array}{l} \diagup N - \\ \\ \diagdown N - \end{array}$$

is of fundamental importance for photographic sensitizing. Photographically[2] active gelatine contains only from 1 part per 1,000,000 to 1 per 300,000 of the sensitizing substance and the presence of such an exceedingly small amount in a complex, many-sided substance like gelatine accounts for the fact that after fifty years we are just discovering the reason for reactions which have been observed since the earliest days of gelatine emulsions.

The sensitizing action of thiocarbamide increases with the concentration up to a certain point, which varies with the particular emulsion, and then falls off. The fog increases steadily with increase in the thiocarbamide, and rapidly after the maximum speed is passed. With a particular emulsion examined by Sheppard, an increase in speed from 19 H. and D. to 3000 H. and D. was recorded, this maximum being obtained with a concentration of 0.0146 g. of thiocarbamide to each 100 g. of silver halide.[3]

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[2] Sheppard, *Phot. J.*, 1925, **65**, 380.

[3] Sheppard, *Phot. J.*, 1926, **66**, 399.

Many other substances have since been found to act as sensitizing agents. Among these are: codein, diethyldiamine,[4] iminazole derivatives (B. P. 271,475 of 1926, I. G. Farbenindustrie), sodium trithionate, tetrathionate (B. P. 255,846 of 1926—I. G. Farbenindustrie) and thiazole and cystine compounds (B. P. 246,800 and 258,237 of 1925—I. G. Farbenindustrie). Increasing the sulphur content of gelatine increases the sensitizing properties and the treatment of gelatine with sodium sulphide or carbon disulphide for such a purpose has been patented by the I. G. Farbenindustrie, B. P. 283,222 of 1927.

Theourea, mustard oil, and most of the above sensitizers are ineffective when the emulsion is kept in a neutral state and digested by boiling rather than ammonia. The I. G. Farbenindustrie, however, find that the gelatine employed in emulsions of this type may be sensitized by the organic disulphides (B. P. 283,223 of 1927).

The Two Classes of Emulsion.—Sensitive emulsions may be divided into two classes: (*a*) those in which the silver halide is formed in the presence of an excess of silver nitrate and (*b*) those in which the silver halide is formed in the presence of an excess of the soluble halide. Aside from wet collodion, the first class consists principally of emulsions for positive printing out processes such as collodio-chloride and gelatine P. O. P. or similar silver printing papers which produce a visible image upon exposure. The function of the excess silver salt is to act as an absorber for halogen. The second class includes both negative and positive emulsions for development and may be further divided into two classes: (*a*) those which are used without further treatment after emulsification and (*b*) those which are submitted to a process of digestion, known technically as *ripening,* for increasing the sensitiveness and the density-giving powers. This process of ripening consists either of treating the emulsion at relatively high temperatures or in the use of ammonia, and will be discussed in greater detail elsewhere. It is sufficient to say for the present that in the preparation of emulsions for positive printing, where a high degree of sensitiveness is unnecessary, ripening plays little or no part, the silver bromide, or silver chloride, being emulsified in such a way as to obtain a very fine grain. In the preparation of highly sensitive emulsions for negative processes, however, ripening plays a very important part.

General Outline of Operations in Emulsion Preparation.—The general outline of the processes involved in the preparation of gelatine emulsion is as follows:

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[4] Lumiere and Seyewetz, *Rev. franc. Phot.,* 1925, **6**, 291.

1. The gelatine is allowed to swell in cold water and finally dissolved by the application of heat.
2. The soluble halide, or halides, are dissolved in water.
3. The required amount of silver nitrate is dissolved in water.
4. The solution of soluble halide is next added to the colloid medium.
5. The solution of silver nitrate is added to the colloid medium.
6. The silver salt and soluble halide unite by double decomposition to form a silver halide. Thus in the case of silver nitrate and potassium bromide the reaction is represented by the following equation:

$$\underset{\text{Silver nitrate}}{AgNO_3} + \underset{\text{Potassium bromide}}{KBr} \rightarrow \underset{\text{Silver bromide}}{AgBr} + \underset{\text{Potassium nitrate}}{KNO_3}.$$

7. Washing, combined with shredding, to completely remove the last traces of soluble salts.
8. The process of digestion; by standing from 10–20 hours at ordinary temperatures or by heating sometimes up to boiling temperature, or treatment with ammonia, in the case of gelatine emulsions.

Usually, in the case of gelatine emulsions, the silver bromide is formed in only a portion of the gelatine, the remainder being added immediately after digestion. In this way the danger of destroying the setting power of the gelatine by heat is avoided.

Light Sensitiveness of the Silver Halides.—The three silver halides used for photographic emulsions are, in order of their sensitiveness to light, the bromide, chloride and iodide. Of the three the bromide is much the more important; the chloride and iodide are never used alone but only in combination with the bromide. Slow emulsions for positive printing in which after processes of ripening play a minor part are usually composed of a combination of the bromide and chloride while high speed negative emulsions contain generally in addition to the bromide a small percentage of iodide. This does not exist separately in the emulsion, however, but enters into the structure of the silver halide grain. As regards ease of reduction by reducing agents such as photographic developers, the order is chloride, bromide and iodide. Silver bromide precipitated in the absence of colloid media such as gelatine is immediately reduced by developers and is therefore mechanically and chemically unsuited for photographic purposes. It was formerly believed that there are several modifications of silver bromide but later work[5] has shown that all the various forms of silver bromide from the colloidal suspensions of ultra-microscopic particles to the microscopically visible particles of 1 to 4 microns in diameter are crystals of the same family and represent simply differences in dispersity or particle size.

The Preparation of Emulsions.—The student will have perceived by this time that emulsion making is a very exacting and complex process which demands, not only a thorough training in the chemistry of colloids and in physical chemistry, but also a large amount of applied knowledge with respect to the operations of emulsion making which can only be gained from actual experience. Our knowledge of the fundamental principles involved in the processes of emulsion making are still unsatisfactory and the subject is in fact more of an art than a science. What we know about the preparation of emulsions and the influence of various factors on the properties of the finished emulsion has been gained entirely by empirical experimentation extending over a long range of years. While constant experimenting has shown the emulsion maker the conditions essential to the preparation of emulsions of high sensitiveness, we know but little of the fundamental causes involved, the ultimate differences which we find from one emulsion to another, and between different particles of the same emulsion. Work on some of these problems is being conducted at the present time and it is probable that some of these points may be cleared up in the near future. Owing to their commercial value it is difficult to say to what extent these matters will become common knowledge.

While in discussing the preparation of gelatine emulsions it will be necessary to divide the subject into three heads—emulsification, ripening or digestion, and washing—it should not be assumed that these operations are entirely separate and distinct and independent of each other, but on the contrary that they are closely related and mutually interdependent upon one another. The sensitiveness of the silver halide grain is influenced by practically every feature of its environment from the time of its emulsification to coating. The concentration and proportions of the various substances, the temperature at which the various operations are conducted, the character of the gelatine used, the alkalinity or acidity of the emulsion during digestion and the time occupied in the various operations, all influence the sensitiveness and character of the emulsion to a marked degree. Thus if emulsification has not been conducted under conditions which are favorable to the formation of relatively large grains of silver halide as well as the proper proportion of the various sized grains, no manner of digestion will produce a highly sensitive emulsion. In other words, it is not possible to convert a low speed emulsion into one of high speed simply by digestion; if an emulsion of high sensitiveness is determined upon, it must be borne in mind from the beginning and conditions provided which are favorable to the formation of the most sensitive grains of silver halide. Hence while for purposes of discussion the various operations will be treated separately, it is to be understood that in reality they are closely related to one another and not separate and distinct as the manner of treatment might indicate.

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[5] Trivelli and Sheppard, *The Silver Bromide Grain of Photographic Emulsions*, D. Van Nostrand, New York, 1921. Wilsey, *Phil. Mag.*, 1921, **42**, 262; 1923, **46**, 487.

Emulsification.—When silver nitrate and potassium bromide are mixed in the presence of gelatine it is usual to use an excess of the latter salt. In the presence of gelatine, free silver nitrate is easily decomposed during the process of digestion and the emulsion fogs on development. In theory, it should be possible to use equivalent amounts of silver salt and soluble bromide so that neither would be in excess, but it is not possible in practice and therefore it is usual to use an excess of soluble bromide. The proper proportion between the two is a matter of dispute. Dr. J. M. Eder, the celebrated Austrian authority who took a very active part in the development of gelatine emulsions, favored a proportion of 5–4. Sir William Abney, the eminent English investigator, favored a ratio of 15–11; while Bennett and Wilson advised 11–7 when using ammonium bromide, and W. K. Burton 42–25.

The presence of excess soluble bromide either during precipitation or subsequently during digestion is an essential condition of that part of the ripening process which consists in growth in the size of the silver halide grain. This is because silver bromide is more soluble in solutions containing a soluble bromide and the greater solubility results in the formation of larger crystals. An excess of soluble bromide also has the effect of reducing the danger of fog in the preparation of highly sensitive emulsions.

In making rapid gelatine emulsions a concentrated solution of silver nitrate is added to a solution of soluble bromide of similar concentration in the presence of gelatine and an excess of soluble bromide. The slight clouding which appears might lead one to assume that the two do not react immediately to form silver bromide but exist separately for some time. This is not so, for it has been found that silver nitrate and a soluble bromide react at once, even in the presence of gelatine, according to the equation

$$AgNO_3 + KBr \rightarrow AgBr + KNO_3.$$

If the emulsion is examined with a microscope from time to time as additional silver solution is added, a gradual growth in the number of silver halide grains is observed. At the same time, it will also be observed that the grains already formed are increased in size, showing that not all of the silver solution added goes to form new grains of silver halide but that some is added to those already existing. Consequently, the grains of silver halide grow, not only in number, but also in size, with the addition of the solution of silver nitrate. The size of the silver halide grain formed depends upon the amount of free potassium bromide present, the temperature and the concentration and rate of addition of the silver solution.

The freshly precipitated emulsion, especially if emulsified at a low temperature and under conditions favoring the formation of very small particles of silver halide, is very fine grained and relatively transparent but is only slightly sensitive. When digested by heat or ammonia its speed increases from 100 to 1000 times.[6]

Gelatino-Bromo-Iodide Emulsions.—The addition of a small percentage of iodide to gelatino-bromide emulsions was advised by Penny in 1878 and was studied in detail by Abney[7] and by Eder.[8]

The use of iodide makes possible a higher degree of digestion without danger of excessive fog and leads to emulsions of higher sensitiveness. Emulsions containing iodide work cleaner than those of pure silver bromide and give brighter negatives with greater contrast and density. The addition of iodide also changes the spectral sensitivity of the emulsion. As the percentage of iodide is increased there is a definite and progressive shift in spectral sensitiveness towards the longer wave-lengths,[9] until the emulsion contains as much as 30 per cent iodide, after which the characteristic spectral sensitivity of silver iodide alone is obtained.

[6] See Eder, *Handbuch der Photographie,* I, 24 (Ed. 1902).

[7] Abney, *Phot. News,* 1880, 174, 196.

[8] Eder, *Ausfuhrliches Handbuch der Photographie.*

[9] Huse and Meulendyke, *Phot. J.,* 1926, **66**, 306.

It was formerly thought that the addition of iodide resulted in the formation of a complex of bromo-iodide of silver,[10] but it is now known that the silver iodide enters into the crystal structure of the silver bromide crystal. X-ray diffraction studies have shown that the effect of silver iodide is to produce an enlargement of the crystal lattice (Wilsey). The increased sensitiveness of silver bromide when mixed with silver iodide is regarded as being due to the state of strain set up by the presence of the silver iodide incorporated in the silver bromide crystal structure.[11] The larger crystals have been found to contain a higher percentage of silver iodide than the smaller.[12] Also in a given emulsion, the large grains are relatively more sensitive than the smaller. While the difference in the percentage of silver iodide present may be the cause of the higher sensitivity, evidence has been obtained which shows that the higher sensitiveness is not due to silver iodide alone.

Digestion.—When first mixed, the emulsion is very slow, no matter what formula has been employed, and quite unsuited for use for anything but contact printing paper. If the emulsion after mixing is allowed to stand at ordinary temperatures for several days the sensitiveness to light increases. Digestion, or "ripening," of the emulsion at ordinary temperatures is known as cold ripening. The degree of sensitiveness thus obtained, however, is still too low for general use.

Rapid negative emulsions may be broadly divided into two classes: (1) acid or neutral emulsion digested by heat, and (2) alkaline emulsions digested with ammonia, or the alkaline carbonates, either alone or in combination with heat. As a rule, the first class are employed only for the slower emulsions and the more rapid emulsions are prepared with ammonia.

The addition of ammonia to the emulsion was advised by Johnson in 1877 but it was not until after the investigations of Eder in 1880 that it was used with much success.[13] Eder also found that the alkaline carbonates, such as ammonium and sodium carbonate could be used in place of ammonia, but neither has been found to be as effective. The ammonia may be added shortly after emulsification and digestion carried out at normal temperature, or by heat, or the emulsion may be

[10] Eder, *Photographie mit Bromsilbergelatine,* 1903, p. 117–122.

[11] Trivelli, *Recueil des Travaux Chimiques des Pays-Bas,* 1923, **42**, 714.

[12] Renwick, *Phot. J.*, 1924, **64**, 360. Sheppard and Trivelli, *Journal of Franklin Institute,* 1927, 827.

[13] *Sitzungsber, Akad. Wiss. Wien.,* 1880, **81**, II, 687.

partly digested by heat and the ammonia added after the emulsion has cooled down to about 30 degrees centigrade. Only a very small percentage of ammonia is required. More than a few per cent increases the grain size unfavorably and produces emulsions which fog easily in development. The exact amount of ammonia which may be employed depends largely upon the type of gelatine used, the conditions under which the silver halides are precipitated and the method of digestion.

The function of ammonia in ripening is apparently closely connected with the formation of the sensitizing substances such as allylthiocarbamide described by Sheppard and Punnett.

Under given conditions of digestion the sensitiveness varies with the hydrogen-ion concentration. With a given emulsion the sensitiveness increases with increasing time of digestion to a maximum point which varies with the pH (or hydrogen-ion concentration).[14]

While it might be concluded that the change in sensitiveness with hydrogen-ion concentration is due to the amount of silver sulphide derived from the silver bromide-thiocarbamide reaction, this does not seem to be entirely the case, for it has been demonstrated that the sensitiveness of an emulsion, which is lowered upon the addition of acid, is immediately restored when the hydrogen-ion concentration is brought back to its original value.[15]

Fog.—Over digestion produces a coarse granular emulsion, the particles of which are visible to the eye in some cases, while the plate fogs in the developer, blackening whether exposed to light or not. All methods of obtaining an extremely sensitive emulsion lead to plates which fog in development. When digested by heat, fog appears earlier in neutral emulsions than in those which are slightly acid and for this reason a trace of acid is sometimes added to make sure that the emulsion is in a slightly acid state. Too much acid, however, is harmful as it delays digestion and affects the gelatine. Alkaline emulsions are completely digested at low temperatures and tend to produce fog if digestion for a high degree of sensitiveness is attempted. The addition of iodide to emulsions tends to prevent fog, as does the presence of an excess of soluble halide, while, as already mentioned, the addition of a trace of acid to emulsions which are digested by means of heat materially reduces the danger of fog. The danger of excessive fog is of course much higher with high speed emulsions than with low: in fact a certain amount of fog is inseparable from an extremely sensitive emulsion, but the amount is so small, under favorable conditions of manufacture, as to be of little consequence.

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[14] Rawling and Glassett, *Phot. J.*, 1926, **66**, 495.

[15] Rawling, *Phot. J.*, 1927, **67**, 42. Sheppard and Wightman, *Phot. J.*, 1929, **69**, 22.

Theory of Digestion.—There is a progressive growth in the size of the crystals of silver halide during the process of digestion. The smaller grains disappear, combining with the larger grains until the largest crystals reach a diameter at times equal to 8 microns. It has long been supposed that the increase in sensitiveness in digestion is connected with, if not directly due to, the growth in the size of the crystals of silver halide, for it is well established that in general the larger crystals are more sensitive than the smaller. On the other hand, it is possible to prepare low speed emulsions having grains which are appreciably coarser than those of most ultra-rapid emulsions. The relation of size of grain to sensitivity may be expressed by saying that the increased size of grain is a *necessary* but not a *sufficient* condition for high sensitivity. The size of grain may be regarded as the *capacity* factor in the production of the sensitizing specks of silver sulphide, or metallic silver, or possibly both combined.

Many theories of the process of digestion have been advanced; the earlier ones postulated the partial reduction of silver halide to subhalide or the formation of a gelatino-silver halide complex, the later ones the formation of colloid silver.[16]

The recent work of Sheppard on the sensitivity promoting substance in gelatine, while it does not exclude the possibility of colloid silver formation as a factor in the process of digestion, makes it clear that an important, if not the primary factor, in the process is the formation of sulphiding sensitizers and their interaction with silver halide to form highly sensitive nuclei of silver sulphite on the silver halide grain.

Eliminating the Soluble Salts.—After the extra gelatine has been added to the digested emulsion, it is well shaken up and then poured out into a porcelain tray and allowed to set. The time required for setting will vary according to the type of gelatine used, the temperature and also the humidity of the surrounding air. Two hours is generally sufficient and often very much less is required. When the emulsion has set it is ready for washing to remove the soluble salts.

[16] Eder, *Ausfuhrliches Handbuch der Photographie*, III, 37 (1890). Luther, *Die Chemischen Vorgange in der Photographie*, 1899. Luppo-Cramer, *Phot. Korr.*, 1904, **41**, 164. Luppo-Cramer, *Kolloidchemie und Photographie*, 1920. Renwick, *J. Soc. Chem. Ind.*, 1920, **156T**, 39; *Brit. J. Phot.*, 1920, **67**, 447, 463.

In dealing with small quantities the emulsion is gathered up in a canvas bag which is placed under the surface of clean cold water and by gentle pressure the emulsion is forced through the interstices of the canvas. For this purpose the canvas should be as coarse as possible. A mesh of about 8 lines to the inch is sufficiently fine. This divides the emulsion up into fine shreds and enables the soluble salts to quickly pass out in running water. Generally the operation is repeated once or twice and the shreds left in running water for one or two hours.

In manufacturing emulsions commercially, presses of the type shown in Fig. 117 for power or hand operation are used. The bottom of the cylinder, which may hold from 15 to 150 liters of emulsion, consists of a nickel-wire screen which cuts the emulsion up into fine shreds. Washing is done in cylinders of about the same capacity through which water is constantly flowing. In some washing equipment, mechanically operated stirrers are provided to keep the shredded emulsion in motion and thus reduce the time required for washing.

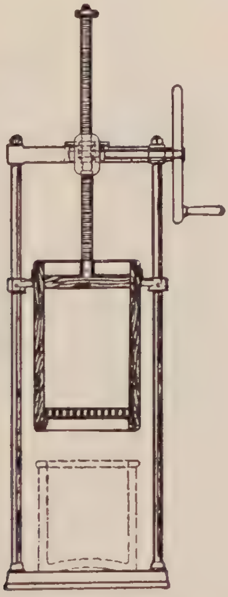

Fig. 117. Emulsion Press and Washer

The emulsion may now be regarded as complete, but it is customary to add a small amount of chrome alum in order to harden the gelatine slightly so that it will adhere to the plate in coating and also remain firm during development, fixing, etc. Since our purpose in this chapter is to discuss the subject of emulsions from a theoretical standpoint and not with the idea of enabling the student to prepare his own plates, the operations of coating, drying and packing will be omitted. For information on these points reference should be made to larger and more comprehensive works on the subject.

The Silver Bromide Grain of Photographic Emulsions.—When examined under a high power microscope, the photographic emulsion is seen to consist of numerous semi-transparent and practically opaque grains of silver halide imbedded in gelatine. These grains of silver halide are definitely crystalline (Fig. 118) [17] and of various forms and sizes; the most constantly recurring forms being triangles and hexagons, some of which are irregular, while all have rounded corners, but occasionally a long rod-shaped crystal is observed. The grains also vary in transparency, some being almost completely transparent while others are nearly opaque. Since the opaque grains behave in exactly the same way as the transparent grains, there is no justification for assuming that they are different substances. In addition to these there are ultra-microscopic grains which are beyond the limit of visibility with the highest power of the microscope. Recent investigation has

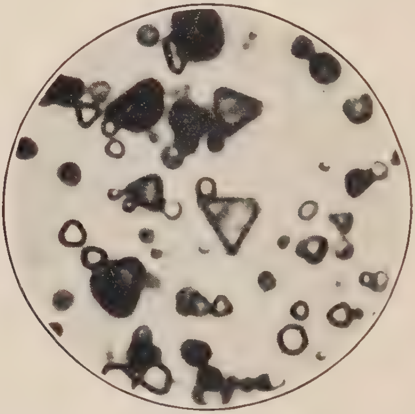

Fig. 118. The Photographic Emulsion under a Microscope

shown that these are also crystalline and have substantially the same structure as those of larger dimensions.[18] There is no evidence for the existence of non-crystalline silver bromide in photographic emulsions.

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[17] The emulsion shown in Fig. 118 has been greatly diluted in order that the individual crystals may be more clearly seen. Ordinary emulsions as used for coating of plates and film consist of many layers of such grains and contain from 10 to 25 billion of such crystals to the square inch.

The size of the silver halide grains in commercial emulsions ranges from the ultra-microscopic particles of less than one micron to grains as large as 3 or 4 microns. In positive emulsions the larger number of grains are either ultra-microscopic or very small, while in the case of highly sensitive negative emulsions, although a large number of ultra-microscopic grains are present, the majority of the grains are of microscopic size, while all are of course definitely crystalline.

The Sensitivity of the Silver Halide Grain.—Microscopical investigation has shown that in spite of the enormous number of grains of silver halide and their close proximity to one another, each individual grain affected by light acts as a single unit and there is no transference of development from one grain to another, unless the two are grouped together in absolute contact; a state of affairs characteristic of some emulsions.[21] It has also been found that a grain is either made developable by a certain amount of light or it is not developable. Thus, we do not get partial development for a certain exposure followed by more for a longer exposure but up to a certain amount of light action the grain is undevelopable and after that amount is reached it is rendered completely developable. The amount of light required to make a grain developable represents what is termed the *sensitivity* of the grain.

Investigation of the number of grains made developable by a given exposure shows that all the grains are not equally sensitive; because under such conditions all the grains would become developable as soon as the exposure reached a certain value. Microscopical examination at high powers shows that the grains of silver halide differ widely in size and on counting the number of grains made developable in given size-classes, it is found that in one and the same emulsion the sensitivity increases with the size of the grain. This does not necessarily mean that all large grains are more sensitive than smaller ones, for with different emulsions the reverse is often true,[22] but if we keep to the same emulsion the larger grains are on the average more sensitive than the smaller. There are, however, differences in sensitivity among grains of the same size and shape in the same emulsion. Sensitivity is,

[18] Wilsey, *Phil. Mag.* (1922), 42, 262.

therefore, not wholly a function of the size of grain, but is due to an inherent difference in the grain itself.

Long ago Abegg and Eder suggested that in the process of digestion a trace of the silver halide is reduced to either a sub-halide, or to silver. These traces they referred to as " ripening centers." These served as centers for further reduction by light to form the latent image. The existence of specially sensitive spots in the grain of silver halide is now well established. Lüppo-Cramer and Renwick supposed these spots, centers, nuclei, or specks, as they are variously termed, to consist of colloid silver.[23] However, the work of Sheppard and his co-workers on the sensitizing substances in gelatine seems to prove beyond all doubt that the sensitivity centers are composed of silver sulphide, which is produced as a result of a chain of reactions between the sensitizing substance and the silver halide (see page 152).[24]

These submicroscopic specks of silver sulphide are distributed at random in, or on the surface, of the grains. It is believed that they cause a strain in the crystal of silver halide creating around them a sphere of weakness in the crystal structure which increases the sensitivity of the grains.

We will leave to a later chapter a discussion of the manner in which these sensitivity centers function in the formation of the latent image.

Grain-Size Distribution and its Relation to the Photographic Properties of Emulsions.—Investigation having shown that the individual halide grain is the photochemical unit of the photographic plate, the properties of the emulsion representing simply the sum of the properties of the individual grains modified by their positions in layers, a study of the effect of grain-size distribution in emulsions and its relation to photographic properties is of great importance. For if emulsion sensitiveness is merely a matter of grain-size distribution the emulsion maker has only to provide the conditions favorable to the growth of crystals of the proper size in order to produce emulsions of the highest possible sensitiveness or having any other required properties. On the other hand, should it be shown that photographic

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[21] Svedberg, *Phot. J.*, 1922, **62**, 183. Slade and Higson, *Proc. Roy. Soc.*, 1920, **A 98**, 154. Trivelli, Righter and Sheppard, *Phot. J.*, 1922, **62**, 407. Trivelli, *Brit. J. Phot.*, 1922, **69**, 687.

[22] Sheppard, *Phot. J.*, 1921, **51**, 400. Renwick, *ibid.*, 1921, **51**, 333.

[23] Lüppo-Cramer, *Kolloidchemie und Photographie.* Renwick, *Brit. J. Phot*, 1921, **67**.

[24] *Phot. J.*, 1925, **65**, 380.

properties are not wholly, or only partially, controlled by grain-size distribution but by other factors as well, the line of investigation must naturally be directed along entirely different lines.

Before 1895 Haddon and Banks called attention to the probability of some relation between the size of grains and the sensitiveness of an emulsion and Mees in 1915 suggested that "inasmuch as emulsions are not homogeneous, but contain grains of all sizes, the sensitiveness of the emulsion will depend upon the distribution of the different sizes of grains, as will also the shape of the characteristic curve."[25] Slade and Higson as the result of some investigations on the action of light on an emulsion containing grains of very nearly the same size and only one layer thick also concluded that the properties of the emulsion are determined mainly by the relation of the different sizes of grains to one another and the quantity of each present.[26] Svedberg found that for every class of grains of nearly the same size in the emulsion there is a distinct characteristic curve.[27]

The matter was not fully investigated in a quantitative manner until 1921 when Sheppard, Wightman and Trivelli of the Eastman Research Laboratory published the first of a series of papers on the subject (see bibliography). They attacked the problem by photomicrographing the grains of various emulsions at a magnification of 2000 times and then enlarging the negative five times, so that the actual magnification equalled 10,000 times. The developed grains of a given area were then measured and divided into classes according to size. The data secured in this manner may be represented graphically by plotting the number of grains of each class as ordinates against the sizes of the grains as abscissæ. In Fig. 119 are shown photo-micrographs of the emulsion of a portrait film and a Standard slow lantern plate together with curves showing the size-frequency distribution of each. It will be observed that the grains of the positive emulsion are all comparatively small and uniform, the range being from about 0.2 to 1 micron. The high speed portrait film, on the contrary, shows an extended range of sizes from about 0.2 micron to as high as 2.7 microns with a maximum close to 0.5.

A correlation of these facts and the photographic properties of emulsions is to be the subject of further investigation. The data which has been accumulated shows definitely that the relative speed of an emulsion increases rapidly with an increase in the average size, and range of size, of the grains contained in the emulsion. Several other interesting relations have been indicated in the course of the investigation and these points are now being investigated. At the present time all that can be definitely stated is that there is apparently a very close connection between grain size and size-frequency and the photographic properties of emulsions.

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[25] *J. Franklin Inst.*, 1915, **179**, 141.

[26] *Phot. J.*, 1919, **59**, 260.

[27] *Z. Wiss. Phot.*, 1920, **20**, 36.

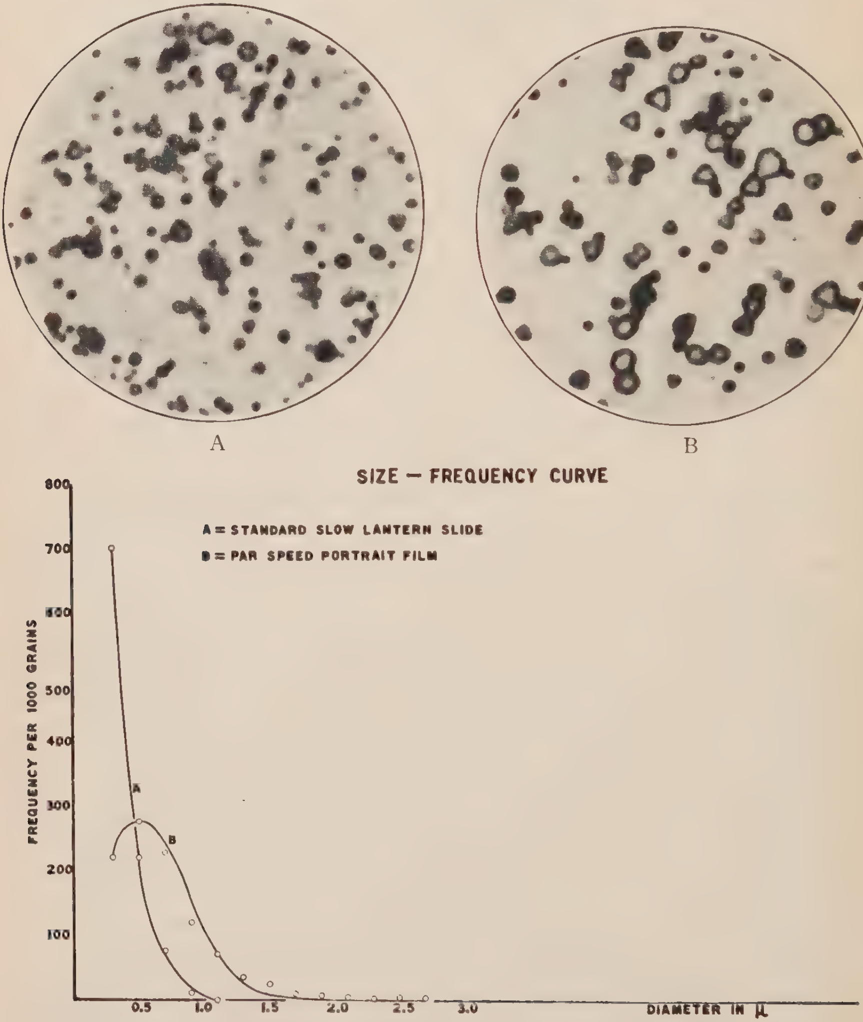


Fig. 119. Size Frequency Distribution of Silver Halide Grains in a Portrait Film and Lantern Slide Emulsion

General Reference Works

ABNEY—Photography with Emulsions.
ABNEY—Treatise on Photography.
ABNEY—Instruction in Photography.
BURTON AND PRINGLE—Processes of Pure Photography.
BROTHERS—A Manual of Photography.
EDER—Ausfurliches Handbuch der Photographie.
EDER AND VALENTA—Beitrage zur Photochemie.
LUPPO-CRAMER—Kolloidchemie und Photographie.
LUTHER—Die Chemische Vorgange in der Photographie.
MEES AND SHEPPARD—Theory of the Photographic Process.
SHEPPARD AND TRIVELLI—The Silver Halide Grain of Photographic Emulsions.
TISSANDIER—History and Handbook of Photography.
VALENTA—Photographische Chemie und Chemikalienkunde.
WALL—Photographic Emulsions.

CHAPTER VII

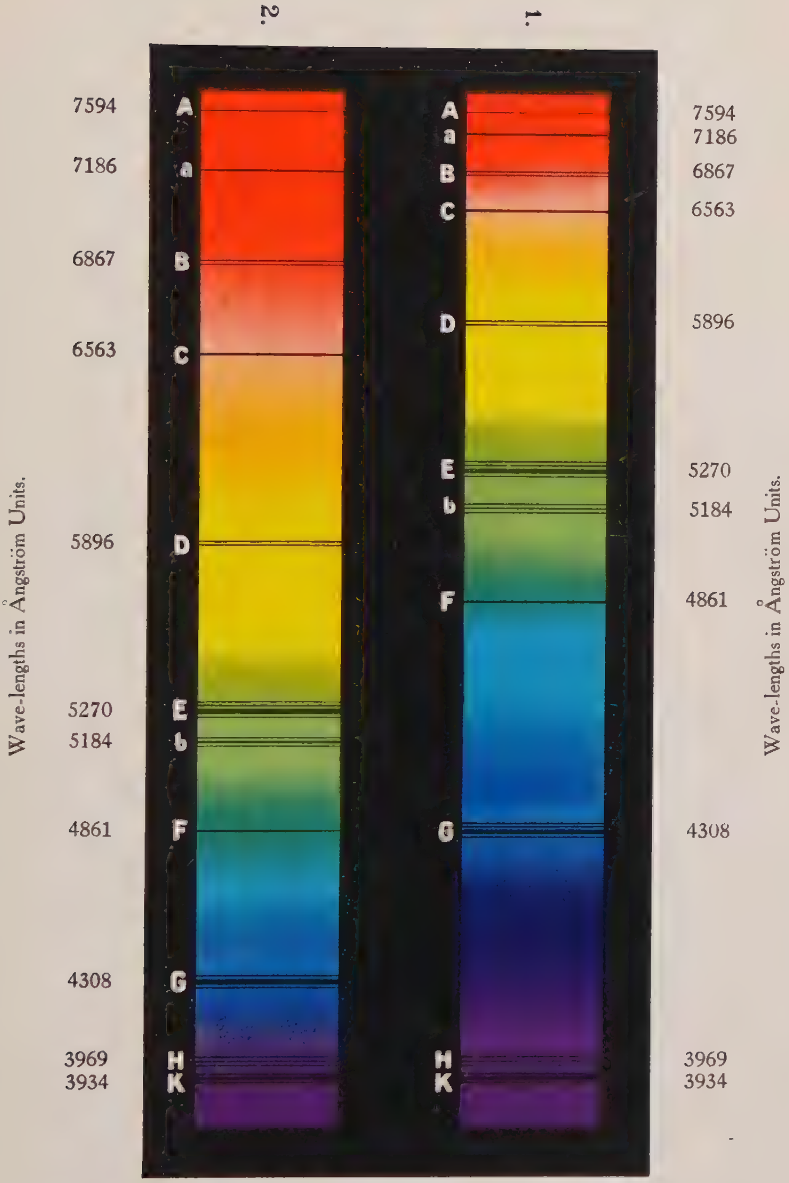
ORTHOCHROMATICS

Light and Color. The Spectrum.—White light consists of a number of wave-movements of various lengths and rate of vibration. When white light is passed through a prism refraction and dispersion take place and the rays are sorted out into waves of different lengths and rate of vibration, producing what is known as the spectrum. The short waves are the most refrangible so that violet is refracted the most and red the least, while green and yellow are refracted to an intermediate extent and occupy a position between the violet and blue on one side and the orange and red on the other. The position of any color in the spectrum in respect to other colors is, therefore, a measure of its refrangibility, or the length of the ether wave.

Although the spectrum consists of a continuous band in which the colors graduate into one another, it is customary to recognize seven colors in the visible portion: violet, indigo, blue, green, yellow, orange and red.

For purposes of reference, it is necessary to have some recognized means of referring to any desired portion of the spectrum. Such a purpose is fulfilled by the Fraunhofer lines. These are narrow dark lines traversing the spectrum and occurring at fixed points so that they form a convenient means of designation for any part of the spectrum. In Fig. 120 the spectrum is reproduced by the three-color process and the positions of the principal Fraunhofer lines are shown. The numbers beside the lines refer to the wave-lengths in Ångstrom units. An Ångstrom unit is equal to 1/10,000,000 of a millimeter and is the unit of measurement used in specifying the length of light waves. As we will have occasion to refer to these lines and wave-lengths, the student should study the three-color print carefully and learn the lines and their relative positions in the spectrum.

Visual and Photo-Chemical Luminosity.—Of the colors which form the visible spectrum, yellow is the most luminous to the eye. The relative visual intensities of the various colors of the spectrum


2.
1.
Wave-lengths in Ångström Units.
7594
7186
6867
6563
5896
5270
5184
4861
4308
3969
3934
A
a
B
C
D
E
b
F
G
H
K
7594
7186
6867
6563
5896
5270
5184
4861
4308
3969
3934
Wave-lengths in Ångström Units.

1. Prismatic Spectrum. — 2. Spectrum produced by diffraction grating.
(Showing the principal Fraunhofer lines.)

FIG. ~~106~~.—Three-color print of the Solar Spectrum.
120

are illustrated in Fig. 121 from Abney,[1] the heights of the curve above the horizontal line giving the relative intensity. It will be observed that the maximum intensity is very close to the D line. On either side of this point the visual intensity of the colors decreases, the drop of the curve being especially noticeable in the blue and violet.

If a sensitive plate is exposed in a spectrograph and the densities, which are a measure of the work accomplished by light, are plotted as above, we will find that the silver halides have a totally different sensitiveness from that of the eye and that the maximum sensitiveness of the plate is found in the violet, while in the yellow near the D line, where the maximum visual luminosity lies, the plate is practically insensitive. It will be still more instructive if instead of an ordinary plate we use the silver halides themselves. Draper, Hunt, Herschel and, more notably, Abney studied extensively this action of the spectrum on the silver halides and the latter gives the following curves which show the sensitiveness of the chloride, bromide and iodide of silver to the spectrum (Fig. 122).[2] The dotted lines indicate the extension of sensitiveness resulting from extreme lengthening of the exposure.

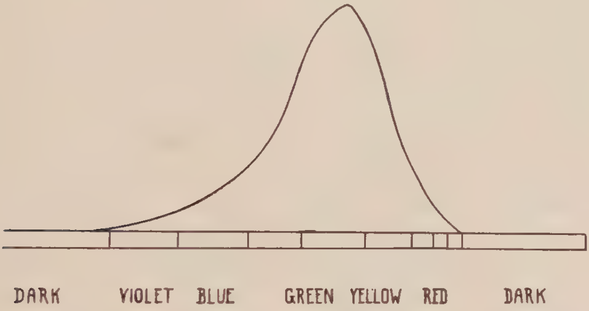


Fig. 121. Visual Luminosity of the Spectrum after Abney

The result of mixing the halides is to secure slightly more sensitiveness in the blue-green but in no case does the increase begin to approach the visual luminosity curve of the spectrum. (See Meldola, *Chemistry of Photography*, p. 208.)

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[1] *Instruction in Photography*, 10th Ed., p. 6.

[2] *Instruction in Photography*, 10th Ed., p. 9. Also see Meldola, *Chemistry of Photography*, p. 255.

Since the visual luminosity of the spectrum is so totally different from the photo-chemical activity of the spectrum, it follows that an ordinary plate containing only the silver halides cannot reproduce colors in their proper relation to one another. Blue objects appear much lighter in photographs than they do to the eye, while yellow is reproduced as black. As a typical example, we may take the case of an orange on a blue velvet cloth. Now of the two, the orange is much the lighter, so much so that the blue appears dark in comparison. When photographed, on an ordinary plate, what do we get? The brilliant orange is a dark grey, almost black, while the blue has turned out almost white and, therefore, the color rendering is totally false. Many other examples might be given to show the false rendering of color given by ordinary plates.

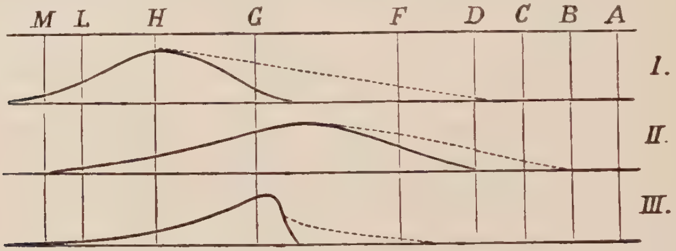

FIG. 122. Spectral Sensitiveness of the Silver Halides. I. Silver Chloride. II. Silver Bromide. III. Silver Iodide

The incorrect rendering of color was for a long time a serious obstacle to the progress of photography but fortunately means have been found which overcome this difficulty and there is now no difficulty in securing proper color values if the proper materials and skill are used. This notable advance has been made possible through the discovery of the fact that certain dyes render the silver halides sensitive, not only to the violet and blue, but also to the green, yellow and red.

Chemical Constitution of Sensitizing Dyes.—H. W. Vogel in 1873 discovered that the sensitivity of the silver halides could be extended to the less refrangible rays by certain dyes.[3] Vogel found that naphthalene red, magneta, methyl violet, cyanin were effective as sensitizers.[4] A number of other dyes were found to act as sensitizers but as these have with but one exception been supplanted by later dyes, we will not stop to consider them here. The exception is eosine, the sensitizing properties of which were discovered by Waterhouse in 1875. This is a powerful green and yellow sensitizer. The fluorescein derivative erythrosine is more generally used, however, for the iso and orthochromatic plates of commerce, owing to its greater sensitizing range especially in the yellow and the beginning of the orange.[5]

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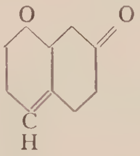
[3] *Ber.*, 1873, **6**, 1302.

[4] *Ber.*, 1875, **8**, 95, 1635.

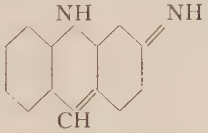
Prior to 1903 the dyes which had been found to function as sensitizers were from widely different classes of dyestuffs. In that year König discovered the sensitizing properties of the isocyanine dyes and since that time the principal sensitizers have been among the cyanines.

The various dyestuffs used for sensitizing are all formed from benzene which is likewise the source of the organic developing agents. Benzene has the formula C_6H_6 and was shown by Kekulé to have a

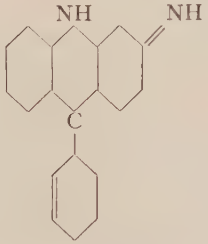
[5] Eosine and erythrosine are derivatives of the xanthene skeleton



which is similar to the parent substance of the acridine dyes,

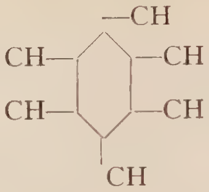


and the flavine group.

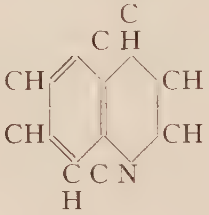


Sensitizers have been found in both of these groups; the cyanines, however, are much the more important.

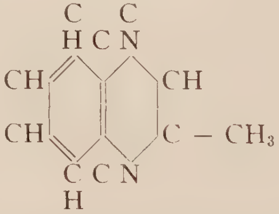
structural formula which may be represented as a hexagon with the carbon and hydrogen atoms linked together around the six points:


—CH
CH—
—CH
CH—
—CH
CH

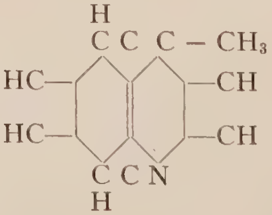
The substitution of nitrogen in the fourth position in the benzene nucleus produces pyridine. The union of a benzene nucleus and


C
C H
CH
CH
CH
CH
C C N
H

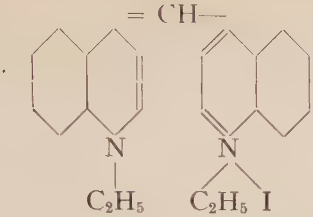
pyridine produces quinoline. The substitution of the $—CH_3$ group for hydrogen in quinoline leads to quinaldine.


C C
H C N
CH
CH
CH
C – CH3
C C N
H

Substitution of the $—CH_3$ group produces lepidine.


H
C C C – CH3
HC—
—CH
HC—
—CH
C C N
H

The cyanines result from the linking of lepidine and quinaldine by a chain of one or three CH groups. When the two are united thus

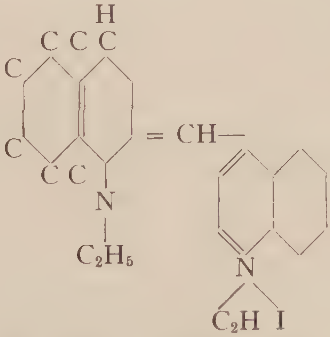


we have the true cyanines.

The sensitizing properties of cyanin were discovered by Vogel in 1875. It was for a long time the only sensitizer for red but on account of its tendency to fog and its general unreliability, it has been completely replaced by the *iso*cyanines and carbocyanines.

In 1903 the first of the isocyanines, Ethyl Red, was introduced.[6] This is an excellent sensitizer which shows a fairly even band of sensitiveness from the ultra-violet to orange. Ethyl Red was followed by a whole series of isocyanine dyes, which surpass it in sensitizing power. These were discovered by König and placed on the market by Farbwerke vorm Meister Lucius and Brüning.[7] These were the sensitizers Pinachrome, Pinaverdol, and Orthochrome T. Similar sensitizers were introduced by Bayer [8] as Perikol, Isokol and Homokol.

In the isocyanines the linking — CH group is substituted in the 2:4′ position; consequently ethyl red (1:1 Diethylisocyanine Iodide) has the formula:



In 1905 another very valuable series of sensitizing dyes, the *carbocyanines*, were discovered by König. These are more powerful red sensitizers than the *iso*cyanines. The best known sensitizer in this class is Pinacyanol. The carbocyanines differ structurally from the isocyanines in that the linking between the two nuclei is effected not by a :CH· group but by the three-carbon chain, :CH·CH:CH. Thus 2:2′—carbocyanine (Pinacyanol, Sensitol Red, etc.) has the formula:

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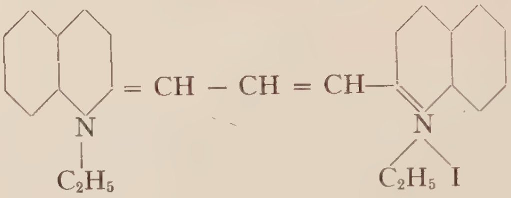
[6] Miethe, *Chem. Ind.*, 1903, 26 (3) 54.

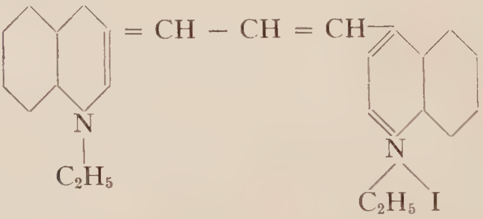
[7] D. R. P. 167,159 and 167,770 of 1903.

[8] D. R. P. 158,078, 170,648 and 170, 049.



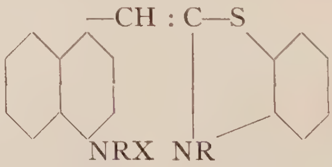
1:1′ Diethyl—2:2′—carbocyanine Iodide.[9]

The 4:4′ carbocyanine



was prepared by Adams and Haller in 1920 and called *Kryptocyanine.*[10] It is a powerful sensitizer for the extreme red and the infra red.

Besides the true cyanines, there are related compounds which are formed when one or both of the quinoline nuclei are replaced by other nuclei. In *thio*cyanine the two quinoline nuclei are replaced by benzthiazole nuclei. No sensitizers of importance have been found in this group but in the thioisocyanines, Mills and Braunholtz[11] have found a series of dyes which are powerful green sensitizers.



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[9] Hamer and Bloch, *Phot. J.*, 1928, **68**, 21.

[10] *J. Amer. Chem. Soc.*, 1920, **42**, 2661.

[11] *Trans. Chem. Soc.*, 1922, **121**, 2004.

[12] *J. Opt. Soc. Amer.*, 1926, **12**, 397

A cyanine, the composition of which has not been described, was separated from Kryptocyanine by Clarke[12] and introduced by the Eastman Kodak Company as neocyanine. It is the most powerful infra-red sensitizer known.

It does not seem possible at the present time to attempt to establish any relationship between the sensitizing properties of a dye and its chemical constitution.

Known Facts Regarding Color Sensitizing.—The most valuable work on the theory of dye sensitizing has been done by Eder from which the following facts are summarized:[13]

1. The dye must stain the silver halide grain.
2. Vigorous sensitizing dyes are substantive dyes. That is, they dye substances directly without a mordant. Staining of the silver halide grain is no proof of color sensitizing.
3. A dye sensitizes for the rays which it absorbs or more accurately the rays absorbed by the dyed silver halide.
4. The maximum of sensitiveness lies at about the same place as the maximum absorption of the dye, with a slight shift towards the red. Stated more correctly, the maximum of sensitiveness agrees with the maximum absorption of the dyed silver halide.
5. A dye having a narrow band of absorption sensitizes a narrow band while dyes having broad bands of absorption give broad bands of sensitiveness.
6. The brilliancy of the dye appears to have no special influence.
7. The sensitizing power of a dye does not appear to be dependent upon either its fugitive character or its fluorescence.
8. No relation can be found between sensitizing power and the chemical composition of the dye.

There are two methods of dye sensitizing: (1) bathing an ordinary blue-sensitive plate in a solution of the dye and (2) incorporating the dye with the emulsion. In general, greater sensitiveness results from the first method but plates prepared by the latter method appear to keep better.

The amount of dye required is very small. The usual degree of concentration varies from 1 part in 1000 to 1 part in 75,000.

It is found that in order to sensitize, a dye must combine with the silver halide. Whether there is chemical or molecular combination we do not definitely know. Eder has elaborated the latter theory,[14] and assumes that the vibrations are absorbed by the colored compound and photochemical decomposition then occurs. The researches of Luppo-Cramer and Traube,[15] if they do not prove the existence of chemical combination between the silver halide and dye, show that there is a very close connection between the two. It is found that it is impossible to remove the last traces of dye from an emulsion even with repeated washings. Moreover, the plate after washing still shows the characteristic absorption and sensitiveness of the dyed silver halide.

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[13] *Ausführliches Handbuch der Photographie*, vol. III, p. 150. *Grundlage der Photographie mit Gelatine-Emulsionen.*

[14] *Beiträge zur Photochemie*, vol. III, p. 75.

Eder's third conclusion is practically the same as Draper's law, which is the foundation of orthochromatics, and states that only those rays can act chemically on a body which are absorbed by it. Light which passes through a substance or is reflected from it cannot have any chemical action.

According to Eder,[16] neither the maximum point of absorption of the dye nor the maximum point of absorption of the dye in gelatine agree with the maximum point of sensitiveness of the dyed silver halide. The maximum photographic sensitiveness lies further to the red by about 20 millimicrons than the maximum absorption point of the dye in gelatine.[17] That dyes having narrow intense bands of absorption would produce similar bands of sensitiveness is to be expected from the third conclusion (Draper's Law) while the reverse would also be expected. It is also well established experimentally by the work of Von Hübl,[18] Monpillard,[19] and Valenta.[20]

Theories of color sensitizing involving the fugitive character of the dye have been advanced. If this was the case, one would expect the dyes having the least stability to light to be the best sensitizers. Examination does not show this to be the case. For instance, cyanin is very unstable while erythrosine is quite stable, yet of the two the latter is by far the most powerful sensitizer. Also, dicyanine is extremely unstable and a weak sensitizer, while rose Bengal is fairly stable and yet a good sensitizer. Evidently then there is no connection between the fugitive character of a dye and its sensitizing action.

It is easily seen how a dye which is fluorescent, if added to the emulsion, might produce color sensitiveness but this theory fails when it is shown that some sensitizing dyes, as erythrosine, are not fluorescent. Many other fluorescent dyes of similar composition are not sensitizers.

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[15] *Brit. J. Phot.*, 1907.

[16] *Beiträge zur Photochemie*, III, p. 35.

[17] This may be explained by Kundt's Law or Wiedemann's theory. See "Recent Work in Color Sensitizing," Wall, *Brit. J. Phot.*, 1907, 51, 406–407.

[18] *Brit. J. Almanac*, 1906, 771, and 1907, 744.

[19] *Bull. Soc. Franc. Photo.*, 1906, vol. 132.

[20] *Beiträge zur Photochemie*, III, pp. 153 and 163.

There is no apparent connection between chemical composition and sensitizing properties. The number of useful dyes is small. Good sensitizers are found in almost all classes of dyes, while dyes differing greatly in stability to light and chemical constitution often show remarkable similarity as sensitizers. While there must be some connection between sensitizing properties and chemical composition such a connection has yet to be discovered.

Color Sensitizing Dyes.—Erythrosine is the most widely used sensitizer for green and yellow although there are other more powerful sensitizers without the decided depression in the blue-green near 520 $\mu\mu$ which is characteristic of erythrosine (see spectrogram in Fig. 123). The advantage of erythrosine over more powerful sensitizers, such as pinaverdol, is that the sensitizing action of erythrosine ends abruptly at 580 $\mu\mu$ while the others continue further into the orange and red. Erythrosine dyed plates can thus be developed in a red light while plates sensitized with the newer isocyanines such as pinaverdol cannot. Pinaflavol, the composition of which has not been published, is one of the few dyes sensitizing specifically for the green. Another is 2-*p*-dimethylamino-styrylpyridine methiodide which was prepared by Mills and Pope[21] in 1922. The sensitizing curve of pinaflavol reaches from about 580–480 $\mu\mu$ with a maximum at about 530. The sensitizing action of 2-*p*-dimethylaminostyrylpyridine methiodide extends to about 600 $\mu\mu$. These green sensitizers are of value more particularly for sensitizing the green plate in three-color photography.

Ethyl Red, the first of the isocyanines, has been completely replaced by the more powerful sensitizers, orthochrome T (*p*-toluquinaldin-quinolinmethylcyanin bromide), pinaverdol (*p*-toluquinaldin-quinolinmethylcyanin bromide) and pinachrome (*p*-ethoxyquinaldin-*p*-methoxyquinolinethylcyanin bromide). Orthochrome T and pinaverdol are essentially green and yellow sensitizers (see spectrograms in Fig. 123). Neither has the depression in the blue-green characteristic of erythrosine. Pinaverdol is a stronger blue-green sensitizer than orthochrome and its action extends farther into the orange, ending at 630 $\mu\mu$. The sensitizing action of pinachrome extends even farther into the red ending approximately at 650 $\mu\mu$. Pinachrome forms an excellent sensitizer for color-sensitive plates where high red sensitivity is not required. For panchromatic plates with a high red sensitivity,

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[21] *J. Chem. Soc.* (London), 1922, **121**, 946.

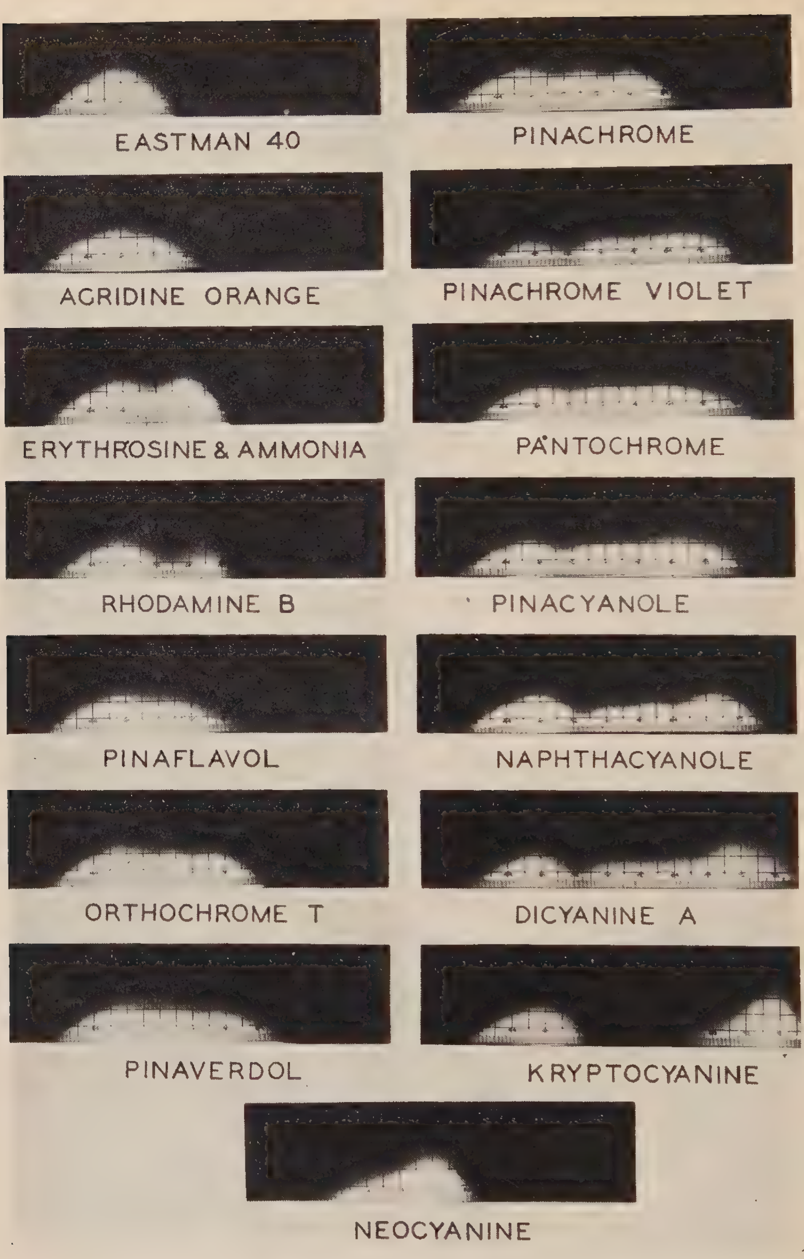

FIG. 123. Spectral Sensitiveness of a Gelatino-bromo-iodide Emulsion, color-sensitized with various dyes

pinachrome is combined with pinacyanol, an extremely energetic red sensitizer, the sensitizing action of which extends to approximately 690 $\mu\mu$ (see spectrogram). As pinacyanol does not sensitize to green it is generally used with pinachrome or pinaverdol to fill up the depression in the green. Pinachrome violet, a later introduction, combines more readily with orthochrome, pinaverdol and pinachrome than does pinacyanol and sensitizes more strongly to red. Pinachrome violet and pinachrome, or orthochrome, make an excellent sensitizer for panchromatic plates where an even sensitizing action from the blue-green to the red is wanted.[22] Pantochrome as a sensitizer resembles pinachrome violet very closely; the sensitizing action, however, is more even, the minimum near 500 $\mu\mu$ being less than with pinachrome violet. Pinachrome blue and pinacyanol blue are two later introductions, the sensitizing action of which reaches farther into the red than does pinacyanol itself; pinachrome blue sensitizing to approximately 680 $\mu\mu$ and pinacyanol blue to 750 $\mu\mu$. Like pinacyanol, neither is a green sensitizer. Napthacyanole (1, 1 diethyl di-β-naphthcarbocyanine nitrate) is a strong red sensitizer which shows a maximum at 690 $\mu\mu$ in the deep red. As a green sensitizer it is even less energetic than pinacyanol and as it does not combine well with green sensitizers, it is suitable principally for work in which high red sensitiveness is required.

Dicyanine was for a long time the only known sensitizer for the extreme infra-red, as with ammonia it has been possible to reach 1000 $\mu\mu$. In order to get good sensitizing, however, ammonia must be added to the dye bath and this tends to produce heavy fog. It is a very difficult dye to work, owing to its erratic behavior, and its use has been confined principally to infra-red spectrography. Dicyanine A is an ethoxylated dicyanine which is slightly more powerful as a sensitizer than Dicyanine. Dicyanine is now being replaced even for spectrography by two later introductions, kryptocyanine and neocyanine. The sensitizing action of the former is greater than that of dicyanine up to 825 $\mu\mu$ beyond which dicyanine is superior. Neocyanine, however, sensitizes strongly to 900 $\mu\mu$ while with longer exposures the mercury line at 1128.8 $\mu\mu$ has been recorded. Both kryptocyanine and neocyanine work clean and free from fog and may be added to the emulsion before coating or used for bathing. Plates sensitized with kryptocyanine are furnished by the Eastman Kodak Company as " Extreme Red Sensitive Plates " and the neocyanine plates as " Infra-Red Sensitive Plates."

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[22] Bloch and Renwick found (*Brit. J. Phot.*, 1920, 67, 304) that aurine (dimethyl-amidoimino-diphenylmethane) which is not in itself a sensitizer increases the color sensitivity of plates sensitized with the isocyanines and carbocyanines and tends to restrain the fogging tendencies of these sensitizers.

Color Sensitizing by Bathing.—Most sensitizing dyes may be added directly to the emulsion before coating and this is the general practice in the preparation of the color-sensitive plates of commerce. Plates bathed after coating in solutions of the sensitizing dyes usually have a higher degree of color sensitivity but, if the evidence available can be accepted, do not keep so well as those in which the dye is incorporated in the emulsion prior to coating.

The dyes used for sensitizing may be purchased in the solid state or in a solution at a concentration of 1 : 1000, except in a few cases in which the dye does not keep in solution. For the experimenter, who requires only a small quantity of a dye, it is best, where possible, to purchase the 1 : 1000 solution. In handling the dye solutions, it should be remembered that they are all sensitive to light so that they should be kept away from strong light.

The character of the plate is one of the most important factors in successful color-sensitizing by bathing. As a rule, ultra-rapid plates are very prone to give excessive fog after sensitizing and medium speed, clean-working plates are to be preferred. There is, however, no way of estimating the suitability of a given plate except by actual trial.

Absolute cleanliness is essential at every point and many of the failures met with in color sensitizing may be traced to chemical contamination. Either a tray or a grooved tank may be used for the sensitizing bath; the latter is obviously the more convenient where a number of plates are to be bathed. In either case the solution should be agitated every now and then or it will settle down. Glass trays, or tanks, are to be preferred as they are more easily kept clean. The tray or tank used to hold the dye solution should be used for no other purpose.

The time of bathing depends to a certain extent on the temperature and more on the concentration of the dye solution. As one never knows what correction to make for higher or lower temperatures, it is best to maintain a temperature of 20 degrees centigrade as closely as possible. At this temperature and for the concentrations given in the table below, the time of bathing ranges from 1 to 5 minutes.

The treatment after bathing varies with the particular dye employed.

Some require a brief rinse in methyl alcohol, others immersion in a weak bath of ammonia; some should be washed in distilled water, others should not be washed at all. The precise treatment to follow in each case is indicated in the table which follows.

Regardless of the particular dye employed, the plate should be dried as rapidly as possible as the rate of drying greatly influences the color sensitivity and keeping quality. With some dyes the plate must be dried in from 1 to 2 minutes if the plates are to keep more than a few days without fog, and in general not more than 5 minutes should be required. A drying cupboard is almost a necessity, but lacking this, one may use one of the electric hot-air dryers as used by hairdressers or an electric fan.

The table on page 182 shows the dilution of the sensitizing dye for stock solutions; the composition of the sensitizing bath and the treatment after bathing. The methods indicated are based for the greater part on a paper by Dundon, Color Sensitizing Photographic Plates by Bathing.[23]

Hypersensitizing of Color Sensitive Materials.—The color sensitiveness of emulsions which incorporate the more efficient sensitizing dyes such as pinacyanol, or a combination of pinachrome violet and pinachrome, is sufficient for all ordinary requirements. There are, however, a few special cases, notably aerial photography, which call for still greater color sensitiveness in order to permit of short exposures with dense, haze-penetrating filters. To reach this end various methods of hypersensitizing color-sensitive plates and film have been worked out. From the practical point of view, all are more or less open to the same objection; namely, the material after treatment does not keep at all well and begins to show fog in a very few days after treatment.

Jacobsohn[24] recommends for the hypersensitizing of panchromatic material a bath consisting of:

Ammoniacal silver chloride, stock solution....................	4 cc.
Distilled water..	200 cc.

This solution will serve for six 9 x 12 centimeter (3½ x 4¾ inches) plates, or their equivalent. The time of bathing at 18 degrees centigrade (65 degrees Fahr.) should be two minutes. The same precautions as to cleanliness and rapid drying must be observed as when sensitizing plates with dyes.

[23] *Amer. Phot.*, 1926, December.

[24] *Amer. Phot.*, 1929, 70; *Brit. J. Phot.*, 1929, **76**, 315.

Composition of Baths for Color Sensitizing by Bathing

(The stock solution of the dye referred to in the table is a 1 : 1000 solution of the dye in methyl alcohol except in the case of Pantochrome, Kryptocyanine and Neocyanine which is 1 : 2000 and Dicyanine A and Naphthacyanole which is 1 : 5000.)

Dye	Sensitizing solution				Remarks
	Water	Stock dye solution	Alcohol	Ammonia	
Erythrosine	100	20		2 (28%)	Immerse in 2% solution of ammonia prior to bathing. Wash 3 minutes after sensitizing.
Rhodamine B	100	10			Time of bathing 2 minutes. Dry without washing.
Pinachrome (Sensitol Green) Orthochrome Pinaverdol Pinacyanole Pinachrome violet (Sensitol violet)	100	2			Time of bathing 3–4 minutes. Rinse well in methyl alcohol after sensitizing and dry as rapidly as possible.
Pantochrome	100	2			Time of bathing 5 minutes. Rinse 1 minute in methyl alcohol and dry.
Naphthacyanole	50	10	40		Time of bathing 5 minutes. Rinse well in methyl alcohol and dry.
Dicyanine A	60	20	20	4 (28%)	Mix water and alcohol and cool to 50° F. Add dye and allow 5 minutes to mix with the solution, then stir in the ammonia. Time of bathing 4 minutes with constant agitation. Rinse in methyl alcohol and dry rapidly.
Kryptocyanine	500	1	2 (1%)		Time of bathing 3–4 minutes. Rinse in methyl alcohol and dry as rapidly as possible.
Neocyanine	75	1	25		Time of bathing 1 minute. Rinse in methyl alcohol and dry rapidly.
Pinachrome violet and Pinachrome	Distilled water 500 Alcohol 250 Pinachrome violet 1 : 1000 7 Pinachrome 1 : 1000 7				Time of bathing 3 to 4 minutes.

The ammoniacal silver chloride solution referred to is compounded by dissolving 1.5 grams (23 grains) silver nitrate in 50 cc. (about 2 ounces) of distilled water. Hydrochloric acid is then added to this solution as long as a white precipitate of silver chloride is seen to be formed. The clear solution is now poured off, the vessel filled with distilled water, shaken, allowed to settle and then poured off. This operation is repeated a second time, after which the precipitate is dissolved in 200 cubic centimeters (7 ounces, 20 min.) of ammonia 0.190. This ammoniacal silver chloride stock solution (which keeps well) is used in preparing the hypersensitizing solution, which does not keep.

By this treatment the general color sensitivity is increased from 2.5 to 7.5 times, depending on the type of plate or film employed.

The Theory of Light Filters.—With our present knowledge of emulsion making it is impossible to make a plate having the same sensitiveness to colored light as the eye. No matter what dye, or combination of dyes, is used the action of the blue and violet remains stronger than it should be. All emulsions are also extremely sensitive to ultra-violet, while this is invisible to the eye. To eliminate the action of the ultra-violet and diminish the action of the violet and blue so as to secure a closer approximation to the sensitiveness of the eye, it is necessary to use colored screens which, by absorbing these colors either completely or partially, cause the less refrangible rays to affect the plate in approximately the same proportion as they do the eye. An orthochromatic filter should, so far as possible, completely absorb the ultra-violet without absorbing any of the visible spectrum completely, but it must absorb the blue and violet to such an extent that the photographic effect on the plate will be equal to the visual effect of those colors. Filters which accomplish these purposes are known as *orthochromatic, compensation, ray,* or *correction* filters.

While in most cases we desire faithful color rendering, there are times when accurate color rendering will not produce a satisfactory result and it is necessary to deliberately sacrifice truthful color rendering in order to bring out the colors satisfactorily. This is due to the fact that there are two kinds of contrast by which objects are picked out from their surroundings by the eye. We may have color contrast where the difference lies purely in color or we may have tonal difference where the color is the same in both cases but the two areas are different in depth. In the latter case, any plate will properly reproduce the contrast provided it is properly exposed and developed.

In the first case, if the two colors, say green and red, are photographed on an ordinary plate, which is insensitive to these colors, both are represented by black and consequently there is no contrast. If a panchromatic plate which is sensitive to the entire visible spectrum is used with the proper compensation filter, we secure a uniform field of gray without any contrast because of the fact that the two areas are different only in color and not in depth or *darkness*. Therefore, in order to bring out the contrast between the two colors, it will be necessary to sacrifice the correct rendering of either the green or red.

If a filter which transmits nothing but green light is placed in front of the lens during the exposure, the green will be reproduced light while the red will be absorbed in passing through the filter and will reproduce dark. If, instead of the green filter, one passing a narrow band in the orange-red is substituted, the red will be reproduced as light while the green is dark because the green rays from the object are absorbed in the filter and fail to reach the plate. Filters which show a narrow band of transmission and are used to pick out colors from their surroundings are known as *contrast* or *selection* filters.

Color Sensitive Plates with Incorporated Filter Dyes.—Regardless of the particular sensitizing dye, or combination of sensitizing dyes used, the added color sensitiveness to the less refrangible rays does not equal that for the blue and violet. If a yellow filter dye is added to the emulsion, this dye will act as a color screen for the depths of the emulsion when coated on a plate or film base. The screening effect on the grains of silver halide next to the surface will be slight, but the screening effect of the dye will become more apparent as we go deeper into the emulsion. Plates in which a yellow filter dye is incorporated to reduce the sensitiveness of the plate to blue and violet light are known variously as self-screen, non-filter, anti-screen, auto-filter, etc. The dye usually used is filter yellow K. Meister, Lucius and Brüning supply a mixture of erythrosine and filter yellow K as Pinortho I, and Pinachrome and filter yellow K as Pinortho II.

Orthochromatic Filters.—A filter which reduces the blue and violet to the point at which the photographic effect of the different colors corresponds to the brightness of the colors to the eye (a condition which may be defined as *perfect orthochromatic reproduction*) is too dense for practical use as the exposure is increased to a prohibitive extent. Consequently, it is customary to consider as a fully correcting filter one which absorbs sufficient of the more active rays to render the photographic action about equal for all of spectrum to which the plate may be considered sensitive.

To find the absorption curve of a filter which will give correct color rendering on a plate or film we require first to know the sensitiveness of the plate to the various colors. If we photograph the spectrum on the plate in question and express in densities, which are a measure of the work accomplished by light, as a function of wave-length, we obtain a curve which shows the sensitiveness of the plate to the colors of the spectrum. Then, if from the ordinates of this curve we subtract those of the curve representing the visual brightness of the spectrum, we obtain a curve showing the absorption which the filter must possess to produce perfect color reproduction with that particular plate or film.

The practical consequences are that for best results the orthochromatic filter for any particular plate or film should be that advised by the maker for his product. Small differences in manufacture lead to differences in color sensitivity even where the same dyes are used; consequently a filter which may be regarded as a fully correcting filter for one plate may not absorb sufficient blue and violet rays to compensate for the lower color sensitivity of another plate.

Since the color filter absorbs the more active rays, its use necessitates an increase in exposure. The amount which the exposure must be increased, under like conditions, when a filter is used is known as the " factor " of the filter. Thus a filter which under the same conditions doubles the exposure required by the plate without a filter is said to have a factor of 2. The factor of a given filter depends upon the light source by which the exposure is made and the spectral range of the sensitive material. The greater the relative intensity of the light source in that portion of the spectrum transmitted by the filter, the lower the factor of the filter. The multiplying factor of the usual yellow filter, for example, is much less with clear, incandescent electric light than with daylight, owing to the greater abundance of long-wave radiation in the former as compared with daylight.

The expression, " a 2 x filter," is meaningless, therefore, unless the plate and the nature of the light source are specified. Where a filter is stated to be a 2 x filter for a certain plate or film, the use of daylight or an artificial light source approximating daylight, i.e., the white flame arc, or blue incandescent lights, is assumed.

The following table will give one an idea of the extent to which the factor of a filter is altered by changes in the light source and the character of the plate.

Factors for a Yellow Filter (K_3) on Ordinary (Portrait Film) on Orthochromatic (Commercial Ortho) and Panchromatic (Commercial Panchromatic Film) to Daylight, White Flame Arc, Clear Mazda Lamp and Cooper-Hewitt Mercury Vapor Tubes

	Ordinary	Orthochromatic	Panchromatic
Daylight	32	12	4.5
White flame arc	8	8	3
Clear Mazda	3	3	1.5
Cooper-Hewitt	20	32	5

The use of any filter in glass alters the focus of the lens, so that focusing should be done with the filter in place. For long focus and telephoto lenses the use of filters cemented in optical flat glass is advisable as filters of ordinary optical glass may affect the definition of the objective.

Orthochromatic Methods in Landscape Photography.—There is by no means complete agreement concerning the value of orthochromatic methods among landscape workers. Some workers pin their faith to an ordinary plate owing to the better representation of atmosphere. Others use color-sensitive plates of the iso type with just enough correction to render the clouds with the landscape while still others insist on complete color correction and use panchromatic plates with fully correcting filters.

The best methods in practice depend upon the results desired. The pictorialist who revels in atmospheric effects of early morn or late afternoon and evening will find the ordinary non-color-sensitive plate better adapted to his requirements than color-sensitive plates because the very deficiency of the plate causes it to emphasize the features which he desires. The appearance of atmosphere is due to the light rays reflected from dust particles in the air and these rays are always either blue or violet, except at sunset or sunrise when they may be tinged with yellow and orange. Ordinary plates are very sensitive to the blue and violet and also the invisible ultra-violet, which is present in the atmosphere to a considerable extent, and, therefore, emphasize any suggestion of atmosphere.

Many workers employ orthocromatic methods only to the extent of securing printable clouds in their landscapes. For this purpose a comparatively light screen is all that is necessary. Full exposure should be given, otherwise the sky portion of the negative is thin and the foreground has excessive contrast, sometimes appearing as if snow was present. The depth of filter will be determined very largely by the strength of the clouds. If these are strongly marked a very light filter is all that is necessary, while stronger filters are necessary for the thin delicate clouds often observed. Care should be taken not to over-correct the sky (which will be done if a strong filter is used), as the clouds lose much of their delicacy and charm when this is done.

For distant views of mountain scenery and over cities with their enveloping haze of smoke and mist and for aerial photography stronger filters are required. Haze results from blue and violet light reflected by tiny particles in the atmosphere and can be removed by the use of filters which absorb the radiation which these particles reflect. The stronger the haze and the lower the initial contrast of the subject, the deeper the filter required. Strong yellow filters requiring from 3 to 5 times increase with panchromatic plates, or film, or the various filters provided for aerial photography enable the photographer to secure practically any details which may be visible to the eye, while the use of deep red filters and highly red-sensitive plates will often enable details to be photographed which cannot be sharply perceived by the eye.

Orthochromatic Methods in Portraiture.—Concerning the value of color-correct rendering in portraiture, Dr. Mees says:[25] "In no branch of photography is the reproduction of colored objects in monochrome of greater importance than in portraiture and in no branch is it in greater danger of being ignored. The flesh tints, with which the portrait photographer is mainly concerned, are chiefly of a reddish nature, while the yellow and brown shades of hair and the variety of eye-colors apart altogether from the clothing cause every sitter to present a distinct problem in color reproduction."

Figure 124*A* is a print from a negative made on an ordinary non-color-sensitive portrait plate. Ordinary plates are sensitive only to the violet and to blue, rays which are almost completely absorbed by the skin. The result is that an ordinary plate fails to reproduce the texture of the skin properly and produces excessive contrast which emphasizes all of its lines and imperfections. The various shades of brown, golden and red hair are difficult to photograph properly and all sorts of dodges are used by operators to secure a passable rendering of the same. In most cases when the proper tint is secured the detail of the shadows in the hair is lost. The wrinkle which exists around the eyes is often a comparatively deep shade of red and is

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[25] *Photography of Colored Objects.*

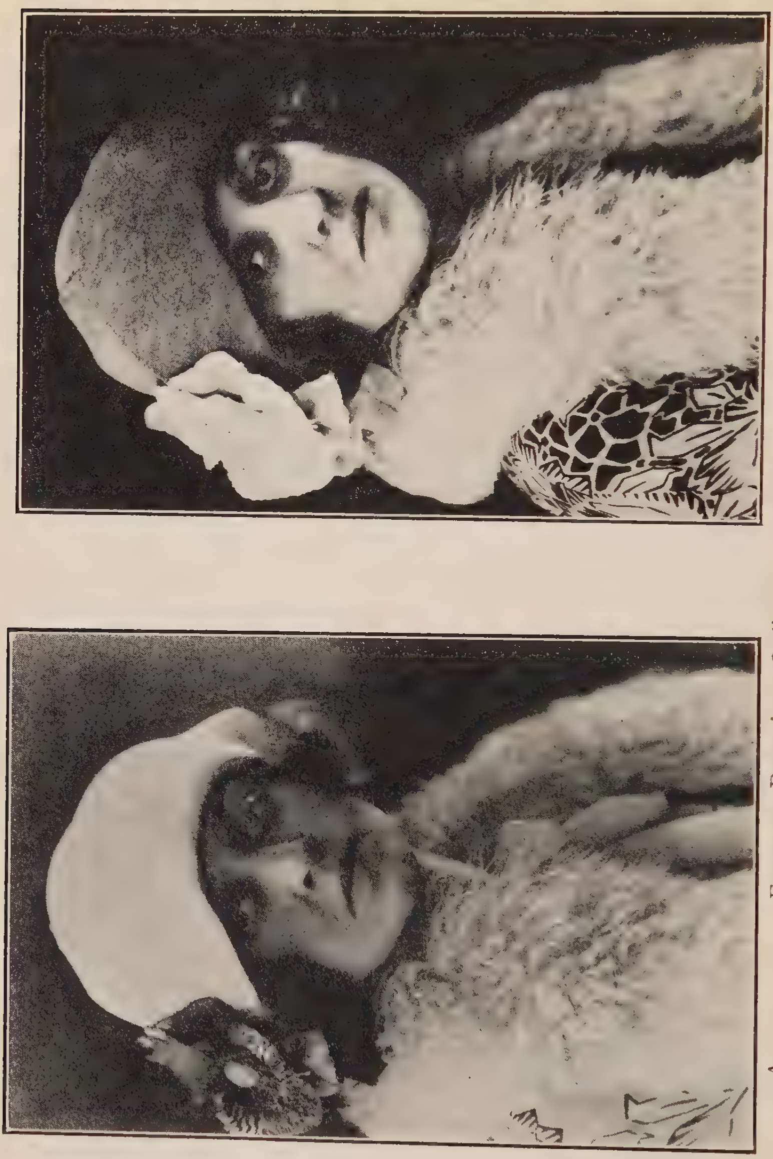


Fig. 124. Portrait on Ordinary and Panchromatic Emulsions

reproduced too dark with an ordinary plate and the retoucher in lightening the same often destroys the strength of the eye by taking out the wrinkle entirely.

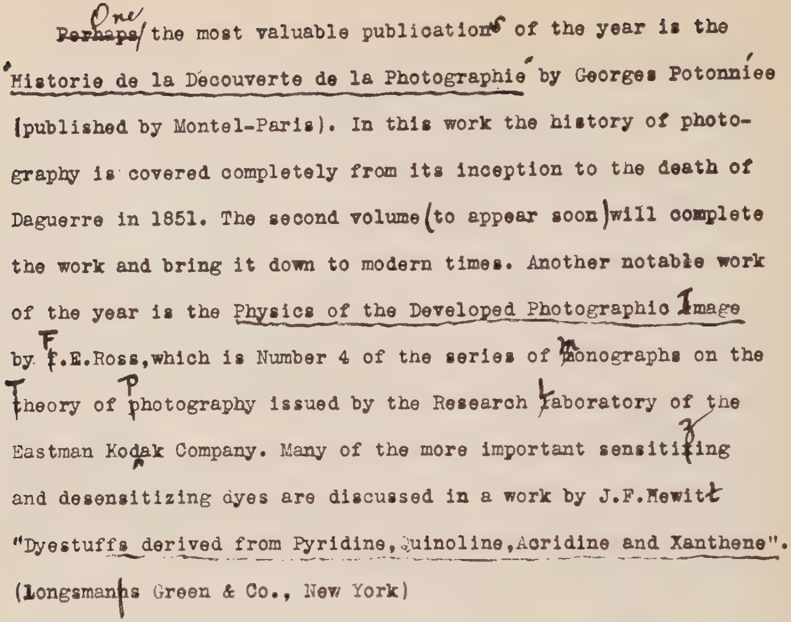
In Fig. 124*B* is shown a portrait of the same subject under identical conditions excepting that a color-sensitive plate and filter were used in making the original negative. The material used was the Eastman Panchromatic film and a K2 filter requiring an increase in exposure of 3½ times. The marked improvement in the rendering of flesh tones and skin texture is quite evident. While the result may not yet be entirely satisfactory and some further retouching may be necessary, considerably less time will be required for this operation since most of the retoucher's work has been done for him, and owing to the comparatively small amount of retouching required on the latter negative there is less danger of losing the facial expression of the subject in that operation.

Ultra-rapid panchromatic plates and film of portrait quality are now available so that there is no longer any real objection to the exclusive use of color-sensitive materials for general portrait work. With daylight, light filters may be used without unduly lengthening exposures while with artificial lights, such as the clear incandescent lamp and the open arc with the so-called "panchromatic" carbons, no filter is required for the average subject. With artificial lights, such as those mentioned, having a great abundance of long-wave radiation, panchromatic materials are distinctly faster than non-color-sensitive materials having the same speed to daylight because they are especially sensitive to the long-wave radiation of these light sources. It is only a question of time before the use of color-sensitive materials will become universal.

Photographing Color Contrasts.—We referred to this subject under the subject of color filters but we now wish to devote some space to the application of the same in practice.

To photograph a color as black a filter must be employed having an absorption band in the wave-lengths of the particular color to be rendered as black. In other words to photograph any given color as black it must be photographed through a sharp cutting filter which completely absorbs the color of the subject. No rays of light reflected from the subject will then reach the plate and the color will be as black as it can be made.

To render a color as white it must be photographed not in its ab-



~~Perhaps~~ One the most valuable publications of the year is the Historie de la Découverte de la Photographie by Georges Potonniée (published by Montel-Paris). In this work the history of photography is covered completely from its inception to the death of Daguerre in 1851. The second volume (to appear soon) will complete the work and bring it down to modern times. Another notable work of the year is the Physics of the Developed Photographic Image by F.E.Ross, which is Number 4 of the series of Monographs on the Theory of Photography issued by the Research Laboratory of the Eastman Kodak Company. Many of the more important sensitizing and desensitizing dyes are discussed in a work by J.F.Hewitt "Dyestuffs derived from Pyridine, Quinoline, Acridine and Xanthene". (Longsmans Green & Co., New York)

FIG. 125*a*. Photograph of Manuscript in Blue with Red Corrections using Green Filter

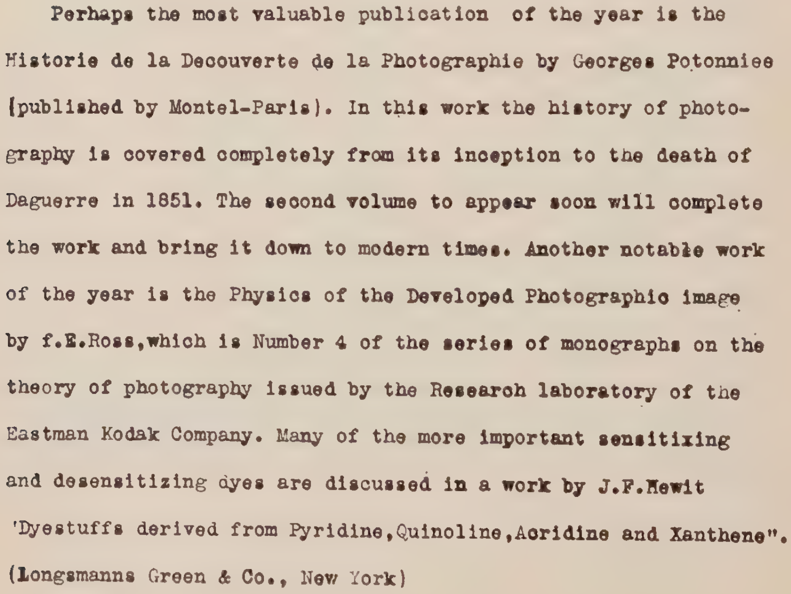


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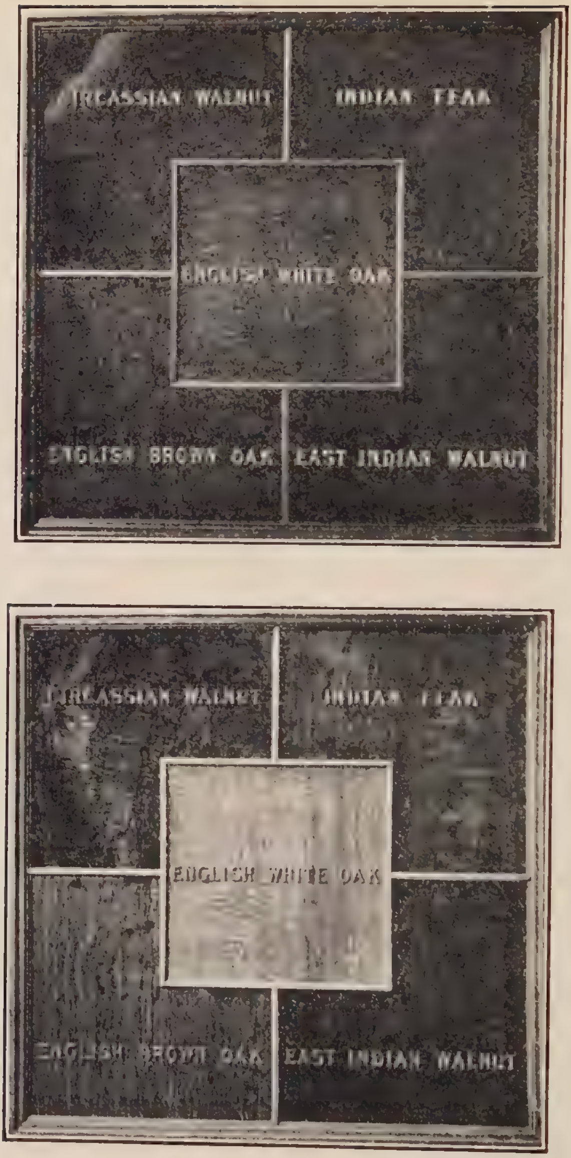
FIG. 125*b*. Photograph of Manuscript in Blue with Red Corrections showing Use of Red Filter sorption band but in its *reflection* band. In other words, any color will be reproduced as light if it is photographed through a filter of its own color.

Red objects absorb blue and green light.
Green objects absorb blue and red light.
Dark Blue objects absorb green and red light.
Yellow objects absorb blue light.
Magenta or purple objects absorb green light.
Light blue or blue-green objects absorb red light.

Suppose, for instance, we have a manuscript typewritten in blue ink with corrections in bright red. We desire to make one photograph showing the manuscript complete with corrections and another showing the text without the alterations. What filters must we employ? If an ordinary, non-color sensitive plate without a filter is employed we will probably find that while the alterations in red stand out while the blue of the original text is quite faint. An orthochromatic plate with a compensating filter will make the blue typewriting somewhat darker but for the greatest possible contrast we must employ a contrast filter which completely absorbs both blue and red. Such a filter would transmit a narrow band in the green and would give us the result shown in Fig. 125*a*. To eliminate the corrections we must reproduce red as white while making blue dark, accordingly we would select a contrast filter transmitting red, such as the Wratten A or F. This would give us the result shown in Fig. 125*b*. Should it be required to photograph the corrections alone, eliminating the original blue typewritten text, this might be accomplished by the use of a dark blue filter, such as the Wratten C.

One of the best examples of the value of orthochromatic methods and the application of the principles of color contrast occur in photographing furniture. In Fig. 126 are shown comparative photographs of wood sections on ordinary and panchromatic plates with proper filters and the immense improvement in results obtained by the use of the latter is at once evident. If red mahogany, for instance, is photographed on an ordinary plate, no trace of the grain is visible, while increasing the exposure merely results in bringing up a large number of scratches imperceptible to the eye. However, by using a panchromatic plate with an orange-red filter the scratches disappear and the grain of the wood is brought out.

In photographing furniture, success depends chiefly upon the selec-


CIRCASSIAN WALNUT
INDIAN TEAK
ENGLISH WHITE OAK
ENGLISH BROWN OAK
EAST INDIAN WALNUT
CIRCASSIAN WALNUT
INDIAN TEAK
ENGLISH WHITE OAK
ENGLISH BROWN OAK
EAST INDIAN WALNUT

On
Ordinary
Plate

On
Panchro-
matic
Plate

(*Courtesy of Ilford Ltd.*)

FIG. 126. Wood Sections on Ordinary and Panchromatic Plates

tion of the proper filter for the subject. For mahogany the greatest contrast is obtained by using an orange-red filter such as the Wratten A. With yellow woods like oak, satinwood, and walnut, the deep yellow filter as the Wratten G will be of greatest service. Care must be taken not to exaggerate the contrast of inlaid furniture and the matter must be compromised, using either a fully correcting orthochromatic filter as the K3 or one of deep yellow or orange-red.

In general it is best to depart from orthochromatic rendering only when absolutely necessary. Whenever there is doubt, it is good policy to make one exposure with an orthochromatic filter in addition to that made with the contrast filter which is judged to be correct.

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Hübl—Die Orthochromatische Photographie.
König—Das Arbeiten mit Farben empfindlichem Platten.
Mees—Photography of Colored Objects.
Weigert—Die Chemischen Wirkung des Lichtes.

CHAPTER VIII

THE LATENT IMAGE

Photo-Physical and Photo-Chemical Change.—Nearly every body undergoes some change when exposed to light. The change may be slow or it may be remarkably rapid, as in the case of the silver halides, according to the nature of the body, and it may be either physical or chemical in character. In the first case the change consists in an alteration of the appearance or properties of the substance but unaccompanied by any change in composition, while in the second case the composition, as well as the properties of the substance, are altered. As an example of a physical change due to the action of light we may take selenium, which in darkness is a non-conductor of electricity but becomes a conductor when exposed to light. Yellow phosphorus, a highly inflammable substance, is gradually converted by the action of light into a red phosphorus with entirely different properties. Powdered non-crystalline selenium gradually becomes crystalline upon exposure to light. Certain metallic salts, such as the crystalline chloride or iodide of silver, nickel sulphate, and zinc selenate, experience a change in crystalline form under the influence of light. In all such cases it should be observed that no chemical change has taken place. Crystalline and non-crystalline selenium are both selenium and have the same composition, while the same is true of the forms of yellow and red phosphorus and of soluble and insoluble sulphur. The change which has taken place is due to some alteration in the arrangement of the molecules but not to such an extent as to cause a chemical change.

Regarding the chemical changes due to light, Eder has made the following general statements:

1. All kinds of light from the ultra-violet to the infra-red, whether visible or not, have some photo-chemical action. The rate of action may vary to a considerable extent, but there is no kind of light that is absolutely without effect on a body if the time is sufficiently prolonged.

2. Photo-chemical action is produced only by such rays as the body absorbs (Draper's Law), so that the chemical action of light is closely related to optical absorption.

3. The sensitiveness of a body towards rays of a definite refrangibility is increased by the admixture of other substances which absorb the same rays.

4. A substance is, as a rule, decomposed faster by a given color when it is mixed with a body which absorbs one of the products resulting from the photo-chemical decomposition.

The action of light may bring about either decomposition or combination. Examples of the former occur in nearly all photographic processes while a familiar example of the latter is the union of chlorine and hydrogen, to form hydrochloric acid according to the equation:

$$H_2 + Cl_2 = 2HCl.$$

Moisture is essential to the above reaction and it is possible that a certain amount of water is required for all photo-chemical reactions.

Thus the action of light may be either reducing or oxidizing in character, depending upon the nature of the substance under its influence.

The Latent Image.—When light is allowed to fall on a photographic plate, or upon silver halide precipitated from solution, the silver bromide is altered in some unknown way because a reducing agent, or "developer," is able to darken the silver bromide exposed to light more rapidly than that which has not been exposed. We say that the light has produced a "latent image" because it is invisible to the eye but susceptible to certain reducing agents, and it is our problem to determine the nature of this change and of what this latent image consists. The nature of the change which occurs when a silver halide is exposed to light is still an unsolved problem, despite much speculation and the enormous amount of experimental work which has been done by the most eminent scientists in an attempt to reach a solution of the problem. While this work has not enabled us to reach any definite conclusion, it has been of very real value as many facts regarding the character and reactions of the invisible image have been established which must of necessity be taken into consideration when forming a working theory of the latent image. Therefore it seems advisable to review some of the more important experimental work by various authorities, which has a definite bearing on the nature and composition of the latent image, before proceeding to a discussion of the theories advanced to explain the same.

Artificial Latent Images.—Towards the end of the last century, W. J. Russell found that many substances were able to act on a photographic plate in some manner so as to make it developable without any exposure to light. The number of substances which would act in this manner was very great, and included freshly scratched metals, especially zinc and magnesium, many fats and volatile oils, and numerous other natural organic bodies like wood, straw, blood and resin. The activity of all these materials was traced to the formation of hydrogen peroxide as a result of the superficial oxidation of the substances in moist air. The vapor and solution of hydrogen peroxide itself exhibited the phenomenon to a much more marked degree.

Since Russell's first experiments, a vast number of materials have been discovered which, when applied to a plate, make it developable in absence of exposure to light. For instance solutions of many mild reducing agents such as sodium arsenite, very dilute ferrous oxalate, sodium hypophosphite and stannous chloride, dilute acids, certain neutral salt solutions and some dyes can all act on a plate to give some sort of latent image. The materials which have been most investigated in this respect are sodium arsenite and hydrogen peroxide. Their actions on the plate show an extraordinary parallelism with the action of light. A study of the fogging action of peroxide and arsenite should, therefore, be of assistance in shedding some light on the nature and formation of the latent light image, and on the nature of the sensitiveness of the grains in a photographic emulsion.

Hydrogen Peroxide.—The action of hydrogen peroxide increases with increase in time of treatment[2] of a plate by a solution of definite concentration, and with increase in concentration of the solution, for a given time of treatment, giving rise on development to a density-exposure curve similar in form to the well-known *ʃ*-shaped characteristic curve for exposure to light. On prolonged treatment with peroxide the curve shows a definite reversal portion, as in the case of light exposure. The characteristic curve for peroxide treatment varies in the same way with time of development as does the normal curve for exposure to light. Plates most sensitive to light are also most sensitive to peroxide, and the bigger grains in an emulsion are, on the average, more sensitive than the smaller ones to both light and peroxide.

Intensification with Hydrogen Peroxide.—Treatment of a plate with hydrogen peroxide at concentrations below that at which fog is produced increases the developability of the image. This fact, first noticed by Lüppo-Cramer,[3] has been studied in detail by Wightman,[4]

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[2] S. E. Sheppard and E. P. Wightman, *J. Franklin Inst.*, 1923, **195**, 337.

[3] Lüppo-Cramer, *Phot. Korr.*, 1915, **52**, 136.

[4] Wightman, *Brit. J. Phot.*, 1927, **74**, 447.

Trivelli,[5] Sheppard[5] and Quirk,[6] of the Kodak Research Laboratories by whom it is termed intensification of the latent image.

Studies of the effect of hydrogen peroxide on single-layer plates show that the number of developed grains in a given area affected by light following treatment with hydrogen peroxide is greater than the sum of those acted upon separately by light and hydrogen peroxide.

If it is assumed that the sensitivity centers of the silver halide grains vary in size and that the effect of light is to increase these centers proportionately, that is to produce latent image centers of various sizes, some of which are large enough to make the grains developable while others are not, then the effect of hydrogen peroxide is evidently to increase the smaller sized latent image centers to the size necessary to render them developable. Just how the hydrogen peroxide acts in bringing this about is still a matter of doubt; the most likely explanation is that the hydrogen peroxide reacts with the small amount of soluble bromide in the plate to set free very small quantities of bromine which according to the theory of Hickman (to be discussed later) reacts with the silver sulphide of the sensitivity speck in such a way as to produce silver and thus enlarge the development center.

The effect of hydrogen peroxide varies with the concentration and time of treatment and is greater for fast plates than for slow. It is prevented entirely by desensitizing the plate in chromic acid or by the removal of the soluble bromide in the plate by the action of silver nitrate.

Intensification of the latent image as produced by hydrogen peroxide is not a property of fogging agents generally as other agents such as methylene blue which produce fog are unable to cause intensification. Silver nitrate appears to be the only other substance possessing this property.

Sodium Arsenite.—Sodium arsenite gives a characteristic curve similar to that for light, and with a well-defined reversal portion. Plates faster to light seem also to be more sensitive to the action of arsenite. The distribution of the latent image due to arsenite treatment has been studied in the same way that Svedberg and Toy studied the distribution of the latent light image due to light, by making statistical measurements on the "reduction centers" shown up by partial development of the emulsion grains. The "reduction centers" in the silver halide grains in an emulsion can be shown up after treatment with arsenite in a manner similar to that in the case of light, and they are found to be distributed among all the grains, and topographically on the individual grains themselves, according to the same laws as are found to hold in the case of exposure to light.

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[5] Wightman, Trivelli, and Sheppard, *J. F. I.*, 1925, **200**, 335.

[6] Wightman and Quirk, *J. F. I.*, 1927, **203**, 261; **204**, 731.

It is possible, by using the *p*-phenylenediamine-silver sodium sulphite mixture, to develop physically, after fixation, the latent image due to sodium arsenite. Treatment of a plate with chromic acid solution desensitizes it to the action of sodium arsenite in the same way as to light action. In the desensitization of a plate to light by chromic acid, it is found that a preliminary exposure to light before bathing in chromic acid greatly accelerates the rate of desensitization. That is, the latent image is attacked by chromic acid much more readily than the sensitive nuclei themselves. The same is found to hold if the "preliminary exposure" is treatment with sodium arsenite solution.[6]

The formation and reaction of the latent arsenite image are thus very similar to those of the latent light image.

Reversal by Light.—With a short exposure to light we get a latent image which on development yields a negative. If the exposure is lengthened considerably the image becomes positive instead of negative when developed, while still further exposure will produce a second negative and it is probable that the cycle may be repeated indefinitely, although owing to the enormous exposures required no one has been able to go past the second negative stage.

No photographic process is, strictly speaking, free from the effects of reversal, but rapid gelatino-bromide plates are more subject to the defect than a comparatively insensitive plate, such as wet-collodion.

The reactions which result in reversal are still obscure; in view of the action of absorbents of halogen such as derivatives of hydrazine and phenylenediamine and sodium nitrite in delaying reversal, it seems possible that it is caused by excess of released halogen, i.e., bromine, which attacks the latent image and reduces the developability of the grain by rehalogenizing the silver nuclei.[7]

Reversal by Chemical Reagents.—The function of exposure of a plate is to affect the grains at the points of sensitivity in such a way that nuclei are formed which are sufficiently big to act as deposition centers for the development process. The function of fogging agents such as have been considered must be a similar one. In the reversal process with light it is probable that the function of prolonged exposure is to make the deposition centers inactive again. It is suggested by some that this could occur by some sort of " retrogressive " action, the centers reverting to their original state; but actually such a reversion seems to be thermodynamically impossible as long as the light stimulus is acting. The more probable result of prolonged exposure is to bring about some " progressive " action which so changes the centers as to make them no longer able to function as centers for development. How this occurs is not clear. In the case of arsenite, however, a very satisfactory explanation is found in assuming that on prolonged treatment the arsenite peptizes the nuclei formed in the first stages of its action, and so makes them too small to function in development. This view is supported by the experimental observation that sodium arsenite can peptize colloidal silver in gelatin, and also that it can destroy the latent image left after fixation of an exposed plate, so that it cannot be physically developed.[8]

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[6] Clark, *Phot. J.*, 1923, 63, 237; 1924, 64, 91.

[7] *Phot. J.*, 1914, 54, 250.

It is seen, then, that although latent image formation is similar in the case of arsenite and of light, the reversal process is probably quite different in the two cases. The presence of the latent image alone is a sufficient condition for reversal by arsenite, but for reversal by light, the silver halide itself must also be present. Hydrogen peroxide solution can also peptize colloidal silver and destroy the latent image, so that an explanation of reversal by peroxide solution similar to that advanced for arsenite is satisfactory. In the case of reversal by exposure to hydrogen peroxide vapor, however, it is more difficult to conceive that it is due to peptization.[9]

Although it is difficult to obtain really direct evidence concerning the way in which many fogging agents act, and results and opinions concerning their action are somewhat conflicting, enough reliable data have been obtained to indicate that the study is of great importance for the theory of photographic sensitivity. In fact, it has played an important part in leading up to the modern conception of sensitivity as due to the presence on the silver bromide grains of traces of some substance not silver bromide.

Photo-Regression.—With a daguerreotype plate, development has to be done immediately after the exposure as the image cannot be retained for more than a few hours and gradually grows weaker after exposure. The same condition of affairs applies to the wet collodion plate, although here the loss of the image may be ascribed to the physical condition of the collodion which requires a certain amount of moisture. With gelatine plates the image is remarkably permanent and instances are on record where gelatine plates have been successfully developed several years after exposure.[10]

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[8] *Phot. J.*, 1924, **64**, 363.

[9] *Phot. J.*, 1924, **64**, 363. Cf. also Wightman, Trivelli and Sheppard, *J. Franklin Inst.*, 1925.

The gradual disappearance of the image after exposure and before development is termed photo-regression, and appears to be a process exactly the reverse of that which produces the latent image. According to Baekeland [11] photo-regression is more apparent on images which have received less than normal exposure. The developing agent used for developing appears to have no effect on the final result. The factors which appear to have the greatest influence on the rate at which the image disappears are temperature and humidity, while the presence of alum or free acid in the emulsion also plays an important part. The higher the temperature and the humidity in which plates are stored after exposure and before development the more rapid is the disappearance of the image. Plates or papers which contain alum, or those in which the emulsion is in an acid state, are more subject to rapid disappearance of the image than plates which do not contain alum, or in which the emulsion is in a neutral or slightly alkaline state. According to Lüppo-Cramer the size of grain has an influence, small-grained emulsions showing regression more rapidly than those of coarser grain.

The phenomenon of photo-regression is interesting in that it shows that the sensitive plate has a certain faculty of self-recovery from the effects of light and any workable theory of the latent image must satisfactorily explain the reason for the same, before it can receive serious consideration.

Action of Oxidizing Agents on the Latent Image and on Sensitivity.—The latent image is either reduced or entirely removed by oxidizing agents. Substances such as potassium cyanide, acid potassium permanganate, acid ammonium persulphate, chromic acid when used with sulphuric acid or potassium bromide and cupric, ferric and mercuric salts, when used with a halide, completely destroy the latent image.[12]

Destruction of the latent image by oxidizers, however, does not necessarily result in the destruction of the sensitivity of the unexposed emulsion. Chromic acid, to name one substance the action of which has been the subject of considerable investigation, reduces the latent image much more than it does sensitivity. With ammonium persulphate the difference is even greater than with chromic acid. The reduction of sensitivity in the unexposed grain by chromic acid varies with the size of the grain, the loss in sensitivity being greater for the large grains than the small.[13] If the sensitivity centers of the grains consist of silver sulphide as indicated by the work of Sheppard, and the latent image of colloidal silver, then it is evident that the difference in the action of certain oxidizers on the latent image and sensitivity can be explained as being due to the greater resistance of the latter to attack. Experiments by Clark[14] on silver and silver sulphide solutions seem to indicate that this is the case.

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[10] H. J. Channon, "Effect of Time on the Latent Image," *Phot. J.*, 1917, **57**, 72. 72.

[11] *Zeit. wiss. Phot.*, 1905, **3**, 58.

[12] Bullock, *Brit. J. Phot.*, 1927, **74**, 590.

Clark found that oxidizers which attack silver sulphide have a strong desensitizing action on certain emulsions but that ammonium persulphate has a much smaller effect. Laboratory experiments on prepared colloidal silver sulphide indicated that it is not attacked by ammonium persulphate, while, of course, it is well known that persulphate dissolves metallic silver. The slight desensitizing action of ammonium persulphate is explained by Clark as being due to the fact that the sensitivity centers do not consist wholly of silver sulphide but of silver sulphide and colloid silver. Persulphate attacks the latter but not the former thus slightly lowering sensitivity. The sensitizing action of colloidal silver as reported by Renwick[15] and Weigert[16] support Clark's assumption that the sensitivity centers consist not necessarily of silver sulphide alone but possibly silver sulphide and colloidal silver.

Physical Development of the Latent Image after Fixation.—If a plate is fixed in hypo directly after exposure one would assume that the image would be destroyed, since hypo is a solvent of the silver halides. Such, however, is not the case for as shown by Young in 1858 with wet collodion and by Kogelmann, Sterry, Neuhauss, Lumière and Seyewetz and others with gelatine emulsion, the latent image is not destroyed by fixing but may be developed in a physical developer, i.e., a developing solution containing in addition to the developing agent a silver salt capable of forming silver in the nascent state.[17]

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[13] Sheppard, Trivelli, and Wightman, *Trans. Faraday Soc.*, 1923, **19**, 306. Clark, *Phot. J.*, 1924, **64**, 91.

[14] Clark, *Brit. J. Phot.*, 1927, **74**, 227.

[15] Renwick, *J. Soc. Chem. Ind.*, 1920, **39**, 156.

[16] Weigert, *Physik. Z.*, 1921, **22**, 674.

Physical development is supposed to be due to the attraction of the nuclei of the latent image for the nascent silver of the developing solution. Assuming this explanation to be correct, then any solution which will reduce a silver salt to the nascent condition should be able to develop the image, although not a developing agent in the commonly accepted sense of the term.

To confirm this point Lumière and Seyewetz [18] tried as a developer a solution of silver sulphite in excess of sodium sulphite and formaldehyde. No image was obtained, however, showing that the nuclei left after fixation are incapable of attracting nascent silver. However, if the fixed-out plate be first immersed in paraphenylenediamine or amidol the nuclei acquire the property of attracting the nascent silver and physical development becomes possible.

From this they concluded that the latent image left after fixing cannot consist of a silver halide, as this would be dissolved in the fixing bath, nor can it consist of metallic silver, unless its property of attracting nascent silver has been destroyed by unknown factors. Owens [19] has since shown that the latent image after fixing probably consists of silver surrounded by silver sulphide so that no deductions as to the nature of the latent image can be drawn from the image which remains after fixing.

The Photosalts.—In 1887, a brilliant American chemist, Carey Lea of Philadelphia, succeeding in preparing compounds of silver chloride which contain less halogen than the original chloride, by treating ammoniacal solutions of silver chloride with ferrous sulphate, washing the precipitate, and then treating with hydrochloric acid. A large number of these compounds were prepared by their discoverer and were called "photosalts," because he considered them identical with the compounds formed when silver chloride is exposed to light. The photosalts were considered to be definite chemical compounds by their discoverer, but most investigators took the view that the combination was more of the character of a "lake," or a physical combination of the altered and unaltered haloids. A theory that the latent image consisted of a solid solution of silver sub-bromide in silver bromide was advanced by Lea himself [20] and was supported by Luppo-Cramer and Lorenz.[21]

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[17] Young, *Photographic News*, 1858, **1**, 165. Kogelmann, "Die Isolierung der Substanz der Latenten, Photographischen Bilder." Graz, 1899. Sterry, *Photography*, 1898, p. 260. Neuhauss, *Phot. Rund.*, 1899, vol. 36, 257 and 1904, vol. 41. Lumière and Seyewetz, *Bull. Soc. franc. Phot.*, 1911, pp. 264, 373; 1924, vol. 169. *Compt. Rendus*, 1924, **179**, 14. Lüppo-Cramer, *Phot. Rund.*, 1924, **61**, 780.

[18] *Phot. Revue*, 1925, **37**, 48.

[19] *Phot. J.*, 1929, **69**, 278.

Some very valuable experimental work on the preparation and composition of the photosalts has been done by a number of German photo-chemists in recent years and especially by Reinders and Weigert.

Image Transference.—According to Renwick, Eder and Pizzighelli in 1881 were the first to show that an exposed silver chloride plate could be converted by treatment with potassium bromide into silver bromide without any loss of the developable condition. In other words it is possible to transfer the latent image from one halide to another without destroying its capacity for development in those parts where the light acted. This phenomenon is known as "image transference." [22]

The Visible Darkening of Silver Halides to Light.—All three of the halides of silver, the chlorine, bromide, and iodide darken visibly on exposure to light. Scheele showed in 1777 that when silver chloride darkens the halogen is liberated. As a result of the work of Schwarz and Gross,[23] and particularly of Hartung [24] using a specially sensitive micro-balance, it is now well established that in the case of all three of the halides, halogen is liberated when the visible darkening takes place. The presence of substances which by absorbing halogen act as "halogen acceptors" increases the degree of darkening and Hartung has shown that silver bromide *in vacuo* in the presence of a bromine acceptor can result in the loss of over 90 per cent of the bromine. The darkening *in vacuo* in the absence of a halogen acceptor is slight and impermanent.

It was formerly believed that the result of the liberation of halogen was the formation of a sub-halide, that is, a halide containing less halogen than the normal. Attempts to prepare definite sub-halides of silver in the laboratory have met with conflicting success, and it appears that the sub-halides of silver which were prepared by Von Bibra[25] and Vogel,[26] for example, are compounds of finely divided silver and unaltered silver halide. The photosalts of Carey Lea were regarded as definite sub-halides by their discoverer but subsequent investigation has shown these to be absorption-compounds of colloid silver with silver halides.

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[20] Lea, *American Jour. Sci.* (3), 33, 1887, 349, 480.

[21] Luppo-Cramer, *Phot. Korr.* (1906), 43, 388, 433. Lorenz, *Phot. Korr.* (1901), 38, 166.

[22] *Brit. J. Phot.*, 1920, 67, 447, 469.

[23] *Z. Anorg. Chem.*, 1924, 133, 389.

[24] *J. Chem. Soc.*, 1924, 125, 2198.

The work of Schwarz and Gross and that of Hartung has at last shown quite definitely that the products of the *visible* decomposition of the silver halide in light are metallic silver and halogen.

The Latent Image.—It is obvious that if we assume that the latent image differs from the visible image which is formed by longer exposure to light, only in degree and not in kind, the latent image could have been regarded as consisting of a sub-halide of silver up to very recent times (1924). Sub-halide theories were supported by a large number of authorities, notably Sir William Abney and Dr. J. M. Eder, who in the earlier editions of his *Handbuch der Photographie* staunchly defended the sub-halide theory.

Others objected that there was absolutely no evidence that a liberation of halogen took place with the short exposures required for the formation of the latent image and pointed to the fact that attempts to prepare silver sub-halides in the laboratory had met with inconclusive and contradictory results, and finally that there was no good reason for assuming that what holds true for the visible image is likewise true for the invisible latent image. The sub-halide theory is now only of historical interest.

Many of those who objected to the sub-halide theory on the ground that the amount of light energy required for the formation of the latent image is insufficient to cause photochemical decomposition as postulated by the sub-halide theory, proposed physical theories which assumed that the result of light was to set up an internal strain within the molecule of silver bromide and cause the atoms to pull apart from each other. The effect of the molecular strain is to render the compound less stable so that it is more easily reduced to metallic silver by reducing agents such as photographic developers. Proponents of such theories pointed out that such reactions could conceivably take place with a very short exposure to light which would be very unlikely to result in actual photochemical decomposition of the silver bromide.

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[25] *J. fur Prak. Chem.*, 2, 12–55.

[26] *Phot. Mitt.*, 36, 334.

The fact that the latent image is formed at extremely low temperatures (— 180° C.) was advanced [27] as additional evidence for a physical rather than a chemical basis of latent image formation.

The x-ray crystal analysis of crystals, however, leads to the conclusion that no chemical molecule, in the sense of a specially combined atom-pair silver bromide exists, but rather a space-lattice of silver ions and bromine ions held together by the electrostatic attractions of the oppositely charged ions, and under such conditions there is little basis for physical theories which involve a molecular strain.

Guthrie in 1850 first advanced the theory that the latent image consists of metallic silver. He thought that the action of light resulted in the formation of small centers of metallic silver on which the image was built up by the further deposition of silver with the developers used for the wet-plate process. Comparatively little attention was paid to this theory until it was revived by Abegg [28] in 1899. The original conception of the metallic silver theory has undergone considerable modification in the past few years and has been transformed into what is termed the *colloid silver* theory.

According to the colloidal silver theory, a sensitive emulsion consists not simply of silver halide in gelatine but a trace of a highly unstable form of colloidal silver in solid solution formed as a result of reduction of some of the silver halide to silver in digestion with heat or ammonia. Renwick advanced the theory that the action of light is to coagulate amicrons of colloid silver to form larger particles which serve as centers for development.[29]

The Modern Conception of Latent Image Formation.—In recent years it has become widely held that the action of light in forming the latent image is to cause the bromine ion in the silver halide to lose an electron, which is then accepted by a silver ion to form a metallic silver atom, so that the latent image consists of small centers of metallic silver on the surface of the silver halide grains of the emulsion.[30] Direct analytical chemical proof of this hypothesis is of course difficult owing to the infinitesimal quantities of silver involved; the only evidence in support of such a hypothesis is that afforded by the chemical reactions of the latent image. These, while not proving that the latent image does consist of silver, are not inconsistent with the view that it is silver.[31]

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[27] Dewar, *Proc. Roy. Inst.*, 13, 695.

[28] *Brit. J. Phot.*, 1899, **46**, 196.

[29] *Brit. J. Phot.*, 1920, **67**, 447, 463.

[30] Sheppard and Trivelli, *Phot. J.*, 1921, **61**, 403. Fajans, *Chem. Ztg.*, 1921, **45**, 666.

Investigations by Toy of the photo-electric properties of the silver halides lend additional support to the hypothesis suggested.[32] It has been known for a long time that the silver halides possess both photo-electric and photo-conductivity properties. By the former is meant the complete liberation of electrons from the salt under light action, and by the latter (sometimes called the internal photo-electric effect) the freeing of electrons internally, resulting in a change in conductivity with the illumination. Theories of the latent image based on the photo-electric effect were brought forward by Allen[33] and by Audubert,[34] but Toy[35] has shown that the silver halides do not show the true photo-electric effect at wave-lengths greater than 280 μ while the photographic effect of light, of course, extends to much longer wave-lengths than this, so that there is, apparently, little foundation for a photo-electric theory of photographic exposure.

While the silver halides do not exhibit the true photo-electric effect under the conditions of ordinary exposure, there are so many striking similarities between the photo-conductivity effect with the silver halides and the photographic effect that one is inevitably led to the conclusion that the latter as well as the former is due to the loosening of electrons from the halide ions.

The photo-conductivity effect is produced with the silver halides by light of practically all wave-lengths to which the same halide is light sensitive. Like the photographic effect, it is influenced but little by extremely low temperatures and can be produced with light of practically the same intensity as is required to produce a developable effect.

The photographic reaction can take place in an exceedingly short time, as is shown by the practical use of exposures of 1/1000 of a second and less. It has been shown by Toy that the photo-conductivity effect can be detected within 0.001 of a second after the illumination is applied and in all probability begins instantaneously with the illumination.[36]

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[31] Bullock, *The Chemical Reactions of the Photographic Latent Image. Monograph No. 6 from the Kodak Research Laboratories,* 1927.

[32] Toy, *The Mechanism of the Latent Image Formation. Proceedings of the Seventh International Congress of Photography,* London, 1928.

[33] *Photo-Electricity, 2d Edition,* p. 247.

[34] *Comp. rendus.,* 1924, **179**, 1046.

[35] *Phil. Mag.,* 1927, **3**, 482.

[36] Toy, *Nature,* 1929, **123**, 679. Sheppard, *Phot. J.,* 1928, **68**, 397.

The Role of the Sensitizing Nuclei.—Until the discovery of the sensitivity centers and the general realization of the essentially disperse nature of the photographic emulsion, all theories of the latent image were based upon the action of light on a homogeneous grain of silver halide. The discovery of sensitizing nuclei consisting of either silver sulphide, or silver sulphide and colloid silver, has added to the problem of the latent image that of sensitivity. There is no longer any doubt of the existence of these sensitizing nuclei and but little doubt that they are composed of silver sulphide, or possibly, silver sulphide and colloid silver. How the nuclei promote sensitivity is another question which is not so clear.

First, it may be pointed out that the sensitizing nuclei cannot be regarded as centers of special sensitiveness, or the spectral sensitivity of an emulsion would be that of silver sulphide and not silver bromide,[37] nor does it appear likely that they act as photocatalysts, accelerating the photochemical decomposition of the silver halide. If the sensitizing nuclei are not in themselves photosensitive, nor can they accelerate the photochemical decomposition of the silver halide, how then can their undeniable influence on the sensitivity of the grain be explained?

Photographic sensitivity implies developability, i.e., a grain is not sensitive unless it can be converted into silver by a developer. Now in order that a grain may be developable it must have somewhere on, or near, its surface a particle of silver above a certain minimum size. Sheppard is of the opinion that the sensitizing nuclei sensitize for *development* rather than exposure. In other words, the effect of the nuclei is not to facilitate the decomposition of the silver halide, but to concentrate the photochemically reduced atoms of silver about themselves so as to form a nucleus of metallic silver sufficiently large to render the grain developable.

It is suggested that these sensitizing nuclei cause in their immediate neighborhood, depending upon their size, more or less strain in the silver halide crystal, resulting in changes in the positions of the electrically charged atoms, or ions, of silver and bromine in the crystal, thus creating spheres of weakness which serve to concentrate the photoeffect around the sensitizing center. According to this theory, the sensitivity centers do not play an active part in exposure. Their role is regarded as being purely passive and a result of the deformation produced by their presence in the structure of the silver halide grain.[38]

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[37] Sheppard, *Third Colloid Symposium Monograph.*

[38] Sheppard, *ibid.*

A chemical viewpoint of the action of the sensitizing nuclei has been suggested by Hickman.[39] According to this hypothesis the silver sulphide nuclei serve as an absorber of the bromine set free by the action of light on the silver halide of the grain surrounding it. This bromine attacks the silver sulphide resulting in the formation of free silver so that the total amount of silver produced is considerably greater than would be formed simply by the action of light on the silver halide. While it may not be impossible for such a reaction to take place under the conditions which probably exist in the silver halide grain, in no investigation of the interaction of silver sulphide and bromine in the laboratory has the formation of silver been observed.

Still another hypothesis of the action of the sensitivity centers has been tentatively advanced by Trivelli.[40] As the silver halides have been shown to be photoconductive, and there is some basis for the assumption that in the silver halide grain there may exist a certain amount of finely divided silver as well as silver sulphide, Trivelli suggests that when light falls on the grain, the greater photoconductivity of the sensitivity nuclei as compared with the halide produces a difference in electrical potential which results in the electrolytic deposition of silver in contact with the sensitivity center and thus assists in building up a particle of silver sufficiently large to render the grain developable.

Useful as these various pictures of the mechanism of the sensitivity nuclei may be as working hypothesis, much experimental work will have to be done before the true facts are established.

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Lüppo-Cramer—Photographische Probleme.
Valenta—Photographische Chemie und Chemikalienkunde.

[39] *Phot. J.*, 1927, **67**, 34.
[40] *Phot. J.*, 1928, **68**, 14, 67.

CHAPTER IX

SENSITOMETRY

What is Sensitometry?—The merest beginner soon realizes that exposure is by far the most important operation in picture making, and the one presenting the greatest difficulties on account of the variable factors which must be taken into consideration in calculating the proper duration of the exposure. One of the most important of these factors is the speed, or the sensitiveness, of the plate to light. Methods by which the sensitiveness of plates are determined come under the heading of *sensitometry*. While sensitometry is concerned primarily with methods of speed determination, this is not its only value, for in determining the speed of the plate we learn a great deal concerning its characteristics and properties, so that we may define sensitometry, in its broadest sense, as the study of the reproduction of light and shade by sensitive materials.

General Resume of Sensitometric Methods.—As early as 1848, Claudet devised an instrument, which was termed a "photograph meter," for determining the speed of the daguerreotype plate. This instrument gave to various portions of a plate exposures which increase in geometrical progression as 1, 2, 4, 8, 16, etc. The shortest exposure producing a visible impression on the sensitive material is taken as a measure of the speed of that material. Thus if the lightest visible deposit on one plate is produced by an exposure of 10 seconds, while the time required for another material is double this, or 20 seconds, the relative speeds of the two are as 1 : 2. This method of determining the speed of plates by reference to the lowest exposure which produces a visible deposit is termed the *threshold* or *Schwellenwert* method. While it obviously gives some idea of the relative sensitiveness of different materials to light, it is not very reliable, except where the mere shape of an object is desired, for the test indicates the minimum exposure required to produce a visible image and is in no sense a guide to the exposure necessary for the proper rendering of gradation. Moreover it is possible to considerably alter the results by variations in exposure and development.

Such was the state of affairs when Hurter and Driffield, two British amateurs, began their classical researches on plate speed determination which resulted in 1890 in the system of sensitometric investigation named after them—the H. and D. system. Briefly the H. and D. system differs from the threshold method in that the speed of a sensitive material is determined from several densities rather than one and affords a better indication of the sensitiveness, properties and characteristics of the plate than can be secured from a single density. Further, the final result is not influenced to quite the same degree by variations in development, or other after treatment. It is hard to estimate the real importance of the work of Hurter and Driffield. Their work resulted in much more than merely a method of determining the speeds of sensitive materials. It is hardly too much to say that it indicated for the first time the *rationale* of the photographic process and that a large part, if not the greater part, of our present conception of the theory of photography had its inception at the hands of Hurter and Driffield.

Instruments for Sensitometric Investigation.—In plate speed determination by the Hurter and Driffield system we need: first, a standard light source for exposing plates; second, an instrument, known as a *sensitometer* or *exposure machine,* for impressing a series of exposures in a definite ratio on different sections of the sensitive material; and third, an apparatus for measuring the deposits obtained upon development of the exposed material.

Standard Light Sources.—Daylight is not suitable for plate speed testing because of its variability both in intensity and color, or spectral distribution. The principal requirements of a suitable light source for plate speed testing are, (1) that it should be accurately reproducible not only in intensity but also as regards spectral distribution in order that the speeds of sensitive materials of different classes as determined in different laboratories may be directly compared, and (2) that it should be reasonably constant in intensity over fairly long periods of time. Hurter and Driffield used the standard English candle; later workers adopted the Harcourt pentane and the Hefner amyl-acetate lamps These sources are easily reproducible and constant but are deficient as regards the color of the light which, as compared with daylight, is distinctly yellowish to orange and consequently higher speed values are obtained for color-sensitive plates than for non-color-sensitive plates having the same speed to daylight.

No unscreened light has exactly the same spectral distribution as daylight although the magnesium flame approaches it closely.[1] A fairly close approximation to daylight is possible, however, with the acetylene flame or incandescent electric light when used in conjunction with suitable filters. To secure a flame of constant intensity and accurate reproducibility, a special burner devised by Mees and Sheppard is generally employed. The light emitted by the acetylene flame is modified by a filter such as the Wratten gelatine filter No. 71 or the Davis-Gibson liquid filter.[2]

The tendency in recent years, however, has been towards the use of standardized incandescent electric lamps. These score on the point of convenience but require careful control as not only the intensity but the color of the light varies with the voltage.[3]

Sensitometers.—Sensitometers, or exposure machines, are used for producing on the sensitive material a series of exposures increasing in a definite ratio. This series of exposures may be produced either by varying the light intensity acting on the different sections of the plate, or by increasing the time of exposure by definite amounts. A series of exposures produced by variation of the intensity of the light is called an *intensity scale* while that produced by varying time is called a *time scale.*

Intensity scales may be produced by (1) varying the distance between the light source and the sensitive material for the different exposures; (2) by using different areas of a uniformly lighted source; and (3) by the use of a series of screens of known absorbing power. The last method is the only one now in general use. These screens are generally made of pigmented gelatine following the suggestion of Goldberg and fall into two classes: (1) the so-called optical wedge in which the gradation from light to dark is continuous; and (2) step wedges consisting of a series of steps of increasing density. Such wedges are widely used to expose the sensitive material for speed determination where extreme accuracy is not essential.[4]

The Chapman Jones plate speed tester (Fig. 127) is an example of an intensity scale. The squares numbered from 1 to 24 are filled with pigmented gelatine of increasing opacity so that each numbered step represents a decrease in exposure to the sensitive material placed beneath as the square root of 2. The plate to be tested is placed behind this scale in a special plate holder and the whole exposed to the light of a standard candle at a distance of one meter (39.37 in.).

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[1] For instructions on the use of magnesium see Eder, *Brit. J. Phot.*, 1925, **72**, 444; *Zeit. phys. Chem.*, 1929, **141**, 321.

[2] *Brit. J. Phot.*, 1928, **75**, 432.

[3] Jouanst, *Sci. et Ind. Phot.*, 1925, **5**, 122. Bailland, *ibid.*, 1925, **5**, 125. Walsh, *Phot. J.*, 1925, **65**, 52.

[4] Goldberg, *Brit. J. Phot.*, 1910, **57**, 642, 664. Ferguson, *Phot. J.*, 1911, **51**, 405. Renwick, *Ibid.*, 1911, **51**, 414.

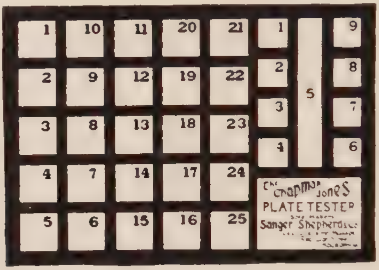

Fig. 127. Chapman Jones Plate Speed Tester

Time scales are realized most easily by the employment of a sector wheel. That of Hurter and Driffield (Fig. 128) contains nine apertures, each angle being twice the preceding, so that the ratio of exposures is in geometrical progression. This revolving wheel is enclosed in a light-tight box carrying at one end the standard light and at the other, behind the sector, the sensitive material to be tested (Fig. 128).

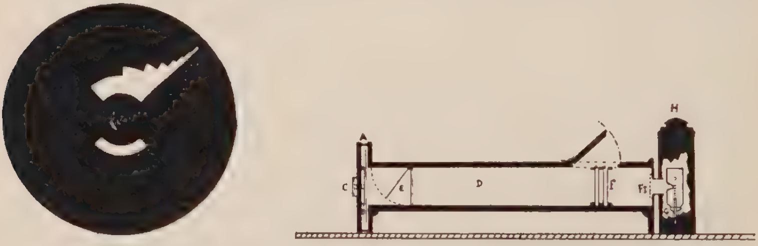

Fig. 128. H. and D. Sector Wheel and Exposing Apparatus

The objection to a sector wheel is that the exposure is intermittent rather than continuous and the photographic effect of an intermittent exposure differs from a continuous exposure of the same length of time by an amount which depends upon the intermittency and the speed of the sensitive material. For this reason time scales producing a continuous exposure are to be preferred. Exposure machines of this class have been devised by L. A. Jones, G. I. Higson and others and are now extensively employed in commercial plate testing.[5]

Relation of Time and Intensity in Photographic Exposure. The Schwarzschild Constant.—Bunsen and Roscoe as a result of their investigations on the darkening of silver chloride papers established what is called the reciprocity law according to which the photochemical effect (or blackening produced) is the product of time and intensity, time being a reciprocal of intensity, or vice versa. It was shown by Abney, however, that the photographic plate does not exactly obey the reciprocity law and that the effect produced by a given exposure depends upon the actual values of intensity and time and not simply on their product.[6]

Schwarzschild, as the result of a series of investigations on the relation of time and intensity in photographic exposure suggested that the relation might be written as [7]

$$E = It^p,$$

where E stands for the effective exposure, or photographic effect; I and t for intensity and time, and p a constant which Schwarzschild thought to be independent of the actual intensities and of the sensitive material.

Later work [8] has shown that for each plate there is an optimum intensity of light which produces the greatest developable effect. The value of this optimum intensity depends chiefly on the speed of the plate or film. In the region of the optimum intensity the reciprocity law is approximately followed; only for lower intensities than the optimum is Schwarzschild's rule approached. It has also been shown that the maximum density developable for a given exposure depends upon the intensity of light acting, decreasing as this becomes less. Lastly, the magnitude of the reciprocity failure increases greatly as the emulsion speed, or sensitivity of the emulsion, decreases and is apparently greater with color-sensitive than with non-color-sensitive materials.

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[5] On the intermittency error see Abney, *Treatise on Photography,* p. 391; Mees and Sheppard, *Investigations;* Formstecher, *Phot. Ind.*, 1927, 25, 575; *Weinland, J. Opt. Soc. Amer.*, 1927, 15, 337; Davis, *Bureau of Standards Scientific Paper, No. 528.*

[6] *Treatise on Photography,* p. 395.

[7] *Phot. Korr.,* 1899, 36, 109, 171.

[8] Jones, Huse, Hall and Briggs, *Proc. Seventh International Congress of Photography,* Heffer, Cambridge, 1929.

There are two consequences of the failure of the plate to obey the reciprocity law which are of importance in sensitometry. The first is that the failure of the plate to obey the reciprocity law is a serious objection to the use of intensity scales such as wedge screens; the second is that the intensity of the light source used for plate speed testing cannot be ignored. In the sensitometers in common use at the present time, the intensity of light is far below the levels usual in actual photographic practice. A " high intensity " sensitometer has been designed by Jones to meet this discrepancy.[9]

Densitometers.—Photometers designed particularly for the measurement of photographic densities are termed densitometers. They may be divided into two classes according to whether they measure the density directly or by comparison with a known density. All densitometers are alike in that they provide means for reducing the intensity of a standard light in a known manner, to match with a similar beam of light which has passed through the density to be measured.

The intensity of the comparison light may be reduced in a known manner by several methods, as for instance (1) by varying the distance of the light, (2) by the use of adjustable rotating sectors, (3) by polarization and (4) by the use of absorbing material such as the optical wedges mentioned previously.

The densitometer employed by Hurter and Driffield in their classical investigations was an instrument of the first class; the well known bench photometer based on the law of inverse squares, the two beams being brought together for comparison on a grease spot, as in the Bunsen photometer which is familiar to every student of elementary physics. Densitometers with rotating sectors were used by Abney and more recently by Jones.[10] The most widely used instruments, however, have been those employing polarization and of these the most popular are the Hüfner and the Martens.

The construction of the Martens densitometer is shown in Fig. 129*a*. One of the beams of light from an electric lamp placed at M proceeds, as shown by the arrow, to the totally reflecting prism q, whence it is reflected through the negative p and is rendered convergent by the lens l passing through the aperture i into the actual photometer head. It then passes through the Wollaston prism, W and the bi-prism Z, then through the nicol N and through the converging lenses h and k to the eye placed at D. The other beam proceeds to the total reflecting prism

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[9] *Proc. Seventh Internat. Congr. Photo.*, Heffer, Cambridge, 1929.

[10] *J. Opt. Soc. Amer.*, 1923, **8**, 231.

p and thence through the Wollaston prism, the bi-prism, the Nicol and reaches the eye at *D*. Thus there is produced at *D* two contiguous fields, one formed by the beam of light which has passed through the density; the other the comparison beam. The intensity of the latter can be reduced by the rotation of the Nicol *N* and the densities determined from the angle of rotation required to produce equality in the two fields.

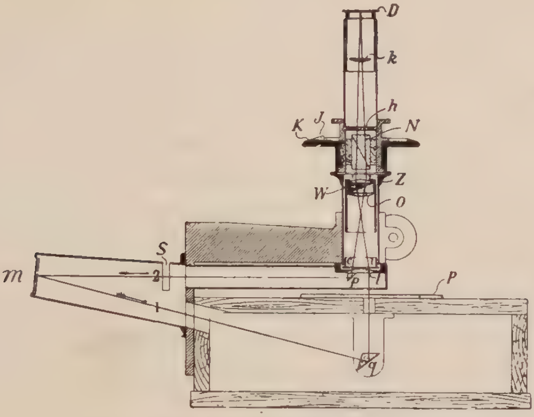

Fig. 129*a*. Martens Densitometers

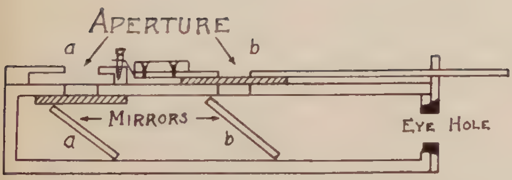

Fig. 129*b*. Sanger-Shepherd Density Meter

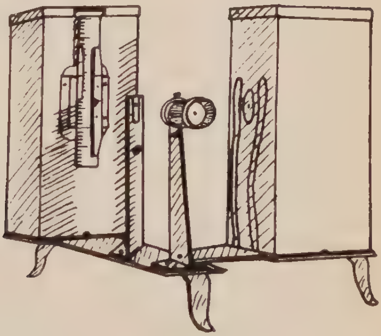

Fig. 129*c*. Filmograph

Densitometers employing absorbing screens, usually in the form of calibrated optical wedges, are more properly termed density comparators, for their measurement of density consists simply in comparison with a known density. A large number of density comparators using optical wedges have been described (see bibliography) and while not quite so accurate as the polarization type in the hands of the expert, have nevertheless found wide employment on account of their convenience. The simpler instruments of this type are perhaps the best adapted of any type of densitometer for student use, being of simple construction, relatively inexpensive, easy to use, not likely to get out of order and sufficiently accurate for all but work of the highest precision. Two inexpensive density comparators well adapted for student use are the Sanger-Shepherd Density Meter,[11] and the Densitomètre Filmograph.[12] The first consists essentially of a shallow, light-tight box (Fig. 129*b*) having in the top two holes, *a* and *b*, under each of which a mirror is fixed so as to reflect the light to the eye-piece at *D*, but the mirror under hole *b* covers only half the hole so that the eye looking in the eye-piece sees a complete circle, one half of which is formed by the light from *a* and the other half from *b*. The density to be measured is placed over *b* and its value determined by adjusting the optical wedge over *a* until equality is obtained.

In the Densitomètre Filmograph (129*c*) the two small cabinets shown each house a 50 watt lamp. The density to be measured is placed over the opening of the lamp-house to the right and the intensity of the light from the other light is reduced by means of the neutral wedge until equality is obtained in the eye-piece.

Although more expensive, two forms of density comparators, the Goldberg Densograph and the Densitomètre Filmograph Enregistreur, which automatically plot the characteristic curve of the emulsion as the densities are measured, deserve mention.

Visual densitometry is to a large extent subject to the personal equation and the same readings are rarely obtained by different workers. On this account the tendency in recent years has been towards the development of physical photometers using photoelectric cells. One instrument of this type, designed by the British Photographic Research Association has proved entirely satisfactory.[13]

It may be pointed out that the density of a photographic deposit is not a definite, unvarying amount but that it depends to a certain extent on the method of measurement. The photographic deposit is not homogeneous, as assumed by Hurter and Driffield, but is a light-scattering medium and consequently the Lambert-Beer law of absorption

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[11] Made by the E. E. S. Color Filter Co., 1 Montague St., London, W. C. 1.

[12] Made by Etablishments Filmograph, 47, rue de Bagneux, Montrouge, France.

[13] *Phot. J.*, 1927, **67**, 176, 324.

(to be referred to later) does not hold. The subject has been completely investigated by Callier, F. F. Renwick and F. C. Toy. It has been shown that densities measured by parallel rays differ markedly from those measured by scattered light secured by placing the deposit in contact with opal glass. Renwick has shown that even then the apparent density is reduced by inter-reflection between the opal glass and the negative.

Opacity-Transparency-Density.—Since we must continually make use of a number of terms having reference to the absorption of light by the developed silver deposit, it is well that we become familiar with the laws governing the absorption of light and the terms used in connection with the same.

Opacity is the term applied to the resistance of a substance to the passage of light. In other words, it may be expressed as the light which must fall on one side of the substance in order that a light of unit intensity be transmitted. Mathematically, this may be expressed as

$$I/I_x,$$

I being the incident and I_x the transmitted light.

Transparency is just the reverse of this, being a measure of the fraction of the incident light which passes through the substance, or

$$I_x/I.$$

I being the incident and I_x the transmitted light as before.

In 1890 Hurter and Driffield introduced the conception of *density*. This they termed the amount of light stopping substance in the deposit and defined as the logarithm of the opacity or the — logarithm of the transparency.

$$D = \log_{10} \text{ (opacity)} = \log_{10} (I_x/I),$$
$$D = -\log_{10} \text{ (transparency)} = -\log_{10} (I_x/I).$$

This conception of the density of a photographic deposit was based upon the Lambert-Beer law of absorption. Lambert's law states that, in passing through equal layers of a material, equal proportions of the light which traverses them are absorbed. Mathematically then, if I is the intensity which penetrates the surface, and I_x the amount which has escaped absorption at a depth of x, then

$$I_x = I^{-kx},$$

where the constant k is the *absorption-coefficient* for that particular substance. This law suggests that absorption is a molecular effect, each molecule absorbing a definite amount of the light incident upon it.

Now in solutions the number of molecules is proportional to the concentration. Therefore the total absorption of a solution depends upon the concentration and the thickness of the layer traversed by the beam of light. If m is the concentration, then the law for absorption in solutions would be expressed as

$$I_x = I^{-kmx}.$$

This is known as Beer's law. From the above it follows that

$$k = \frac{\log I - \log I_x}{mx}.$$

When logs are taken to base 10, k is called the *absorption constant,* or, as defined by Hurter and Driffield, the *density.*

Within certain limits density is proportional to the mass of silver per unit area, or $D = pM$, where D is the density, M the mass of silver and p a constant termed the *photometric constant.* For an area of 100 square centimeters having a density of 1, Hurter and Driffield obtained a value for p of .0131 gram of metallic silver. Eder obtained .0103 and Sheppard and Mees .01031.

FIG. 130. Illustrating the Relation of Opacity, Transparency and Density

Perhaps the relation of opacity, transparency and density may be made plainer with the aid of the following step wedge (Fig. 130). In this we have four sections of increasing density, each additional density being due to the superimposition of an equal density. That is to say, in section 1, we have no silver deposit; in section 2, a silver deposit of a definite value; in section 3, two such deposits and so to N layers. The table on opposite page then shows the relation between the opacities, transparencies and densities of the various sections. The first line gives the number of layers of silver deposit. The second line shows the *transparency* expressed as powers of the fraction which

Light of Intensity I

No. layers of silver deposit	0	1	2	3	N
Transparency	$\frac{1}{1}$	$\left(\frac{1}{3}\right)^1$	$\left(\frac{1}{3}\right)^2$	$\left(\frac{1}{3}\right)^3$	$\left(\frac{1}{3}\right)^N$
Transparency	$\frac{1}{1}$	$\frac{1}{3}$	$\frac{1}{9}$	$\frac{1}{27}$	$\frac{1}{(3)^N}$
Opacity	1	3	9	27	$(3)^N$
Density	0	.477	.954	1.43	——

is the transparency of one film. The third line shows these multiplied out, and the fourth gives the inverse of these or the *opacity* while the last line gives the log to a base of 10, or what Hurter and Driffield term the *densities.*

Exposure and Development of the Sensitive Material for Speed Determination.—Before proceeding with the exposure of the sensitive material for the purposes of speed determination it is necessary to adopt a standard unit of exposure. The photographic effect of a given exposure depends upon three things: the intensity of the light source; its distance from the sensitive material, and lastly the duration of the exposure. Hence the standard unit of exposure must concretely specify the unit intensity of the light source, its distance from the sensitive material, and the unit of exposure. The standard adopted by Hurter and Driffield and now accepted as an International standard is the Candle-Meter-Second (C. M. S.) which means the exposure of the sensitive material for one second, to a light-source with an intensity equal to one candle power, at a distance one meter from the light.

The material to be tested is first cut into strips 1 x 4¼ inches, the strips of sensitive material being preferably cut from the center of a large specially coated sheet in order to avoid any irregularity in the thickness of the coating. Two of the strips are placed in a specially made plate holder which is placed in the exposing machine. Only a small section of each strip is exposed, the remainder being reserved as a " fog strip " which is used to determine the density due to the fogging of the emulsion. This fog density is subtracted from the total densities as obtained from the densitometer readings in order to get the true densities due to the action of light on the sensitive material.[14]

[14] The fog density as determined from the unexposed strip is assumed to be the same over the entire plate regardless of the density. It has been found, how-

The exposure completed, the test strips are ready for development. As the speed of an emulsion varies to a certain extent with different developing agents and different concentrations of the same developer, it is necessary to adopt a standard developing solution if the results are to be comparable. A suitable formula is as follows:[15]

Paramidophenol hydrochloride	7.25	g.
Sodium sulphite (anhydrous)	100.0	g.
Sodium carbonate (anhydrous)	100.0	g.
Water to make	1000	ccm.

No soluble bromide may be added to the developing solution as, due to its restraining action on the lower densities, it introduces an element of uncertainty which is best avoided.

In practice two strips are usually developed at the same time, but one for twice the time of the other. The reason for this will appear later.

It is most important that the test strips be uniformly developed. It has long been recognized that when the test strips are developed in a tray in the ordinary manner, development is by no means uniform over the entire strip, resulting in erratic density values. Rapid distribution of the developing solution over the strips is necessary and to secure more uniform development than is possible simply by rocking the tray, Clark suggested the use of a deep dish and a comparatively large volume of developer kept in motion by a broad, soft-haired brush passed repeatedly over the surface of the plate. This does no damage if correctly used and results in very uniform development.[16]

The temperature of the developing solution should be 65° Fahr. This temperature is maintained by placing the tray or tank holding the developing solution in a large water bath the temperature of which is controlled by a thermostat.

After fixing, washing and drying, the densities of the various portions of the strips are determined by measurement in the densitometer,

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ever, that fog decreases with increased densities so that the addition of density due to fog cannot be eliminated by subtracting a uniform amount from all densities. On the subject of fog correction, see: Wilsey (*Phot. J.*, 1925, **65**, 454) and Pritchard (*Phot. J.*, 1927, **67**, 447).

[15] Sheppard, *Proc. Seventh International Congress of Photography*, London, 1928.

[16] Tank developing apparatus in which agitation is secured by the use of plungers or stirring have been described by Harrison and Dobson (*Phot. J.*, 1925, **65**, 89) and Sheppard and Crouch (*Proc. Seventh International Congress of Photography*, London, 1928).

every precaution being taken to eliminate all sources of error so as to obtain the most accurate measurements possible. A note of the various densities and the duration of the exposure which produced them is made as each density is measured and with this information we are in a position to see what has been the reaction of the plate to the various exposures.

The Relation of Exposure and the Growth of Density.—A strip exposed in a sector sensitometer contains nine exposures, a range of 1 : 512. This range is amply sufficient for the purposes of speed determination, but as we wish, for purposes of demonstration, to investigate the effect of increased exposure on the growth of density over an even wider range we will assume that a number of strips have been exposed in such a way that we have obtained a range of exposures from 1 C. M. S. to over half a million C. M. S. In the table below we have placed opposite this series of exposures the densities obtained by Hurter and Driffield in an actual test. (See H. and D. Memorial Volume, p. 103.)

Exposures in C. M. S.	Densities	Difference
1	.060	—
2	.160	0.100
4	.340	0.180
8	.500	0.160
16	.715	0.215
32	.940	0.225
64	1.345	0.405
128	1.875	0.530
256	2.290	0.415
512	2.535	0.245
1,024	2.985	0.450
2,048	3.115	0.130
4,096	3.280	0.165
8,192	3.405	0.125
16,384	3.508	0.103
32,768	3.474	—0.034
65,563	3.280	—0.194
131,072	3.128	—0.152
262,144	2.920	—0.208
524,228	2.464	—0.456

If you have had the patience to go through the above table carefully, as you should do, you will observe that at first every time the exposure is increased there is practically an equal increase in the density, finally the increase in density for each additional increase in exposure becomes practically a constant and the differences in the last column show no change, excepting of course that due to experimental errors, and finally the growth of density for each additional exposure begins to grow less and less until a point is reached where additional exposure *decreases* rather than increases the total density.

The Characteristic Curve.—It is rather hard to get these points clearly fixed in the mind when the results are set up in tabular form. It is much easier to comprehend this relation between exposure and density by graphic presentation. This might be done by plotting density against exposure but in practice the density is plotted against the *logarithm* of the exposure instead. There are two reasons for this: (1) The range of the two variables is quite different, for while the densities run to about 3, the exposures range as high as a half-million C. M. S., so that no real information can be secured from a curve in which density is plotted directly against the exposure. (2) There is no simple law between exposure and density so that no part of the curve will be a straight line representing an equal addition of density for each increase in exposure. Accordingly the density is plotted against the *logarithm* of the exposure instead of against the exposure directly.

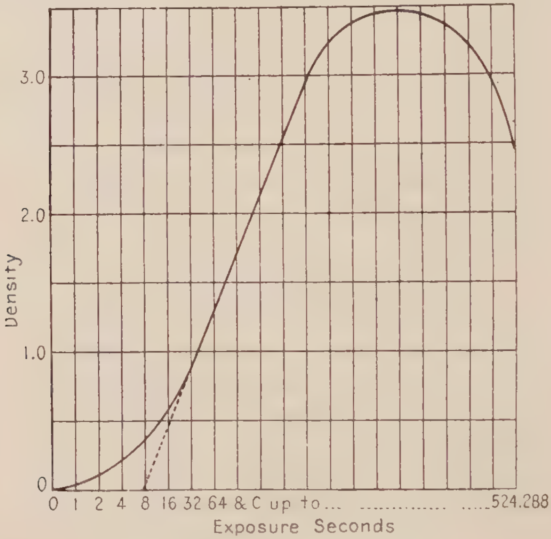

Fig. 131. The Characteristic Curve

The exposure-density relation when plotted out in this manner produces what is termed the *characteristic curve* of the emulsion and takes the general form illustrated in Fig. 131. It represents graphically the growth of density with increased exposure and summarizes in a handy and tangible manner most of the physical characteristics of the sensitive material, so that once we have obtained the characteristic curve of any material we are in a position to predict, not only its speed, but its various other characteristics.

The Significance of the Characteristic Curve.—In an effort to bring home to the student in a still simpler manner the real significance of the characteristic curve we will attempt to explain the various relations with the aid of Fig. 132. In this the steps are supposed to represent the various exposures and their height the amount of the corresponding density. We have divided the entire curve into three divisions, the significance of which we will shortly explain.

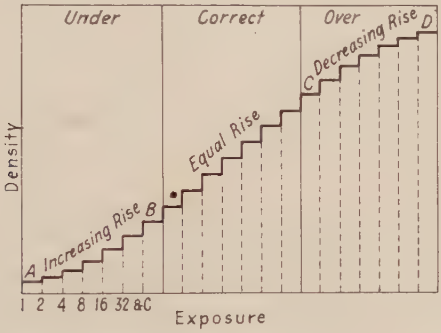

FIG. 132. Step Chart Illustrating the Theory of the Characteristic Curve

The first period is characterized by a rapid increase in density as the exposures increase, the increase in density being approximately proportionate to the increase in the exposure. The relation existing within this period is shown by the following results of Hurter and Driffield:

Exposure 20 C. M. S. (1)...........Density, .125............Relative, 1.
Exposure 160 C. M. S. (8)...........Density, 1.055............Relative, 8.4

With increasing exposures we reach the second period in which the addition of density for each increase in exposure becomes to all intents and purposes a constant. Within the limits of this period, represented by the straight line portion of the characteristic curve (Fig. 131), each time the exposure is doubled there is an equal addition to the density. That is to say that while the exposures increase in *geometrical progression* the densities increase in arithmetical progression, or for example:

Exposures	1	2	4	8	16	32	64	128	256
Densities	0	1	2	3	4	5	6	7	8

This relation between exposure and density has a special significance of great importance which will appear later.

Passing on to the third period it will be observed that the steps are growing less and less for each exposure and finally a point is reached where there is absolutely no increase in density, after which increased exposure results in a decrease in density. This last portion of the curve (not shown in Fig. 132) known as the period of reversal is of great theoretical importance but, as it is reached only with enormous exposures, it has no significance in practice and thus we leave it, referring the student to the literature of the subject for further information.

Inertia as an Inverse Measure of Speed.—When the straight line portion of the characteristic curve is produced so as to cut the log E base line, as shown in Fig. 131, an exposure is indicated which was termed by Hurter and Driffield the *inertia*. The inertia is an inverse measure of the speed of the plate: that is to say, a slow plate has a high inertia while a rapid plate has a low inertia.

The precise significance of the inertia as a measure of speed is somewhat difficult to define. The exposure which it represents is not the "threshold exposure" (the minimum exposure necessary to produce a measurable density) nor does it indicate the maximum exposure which will give proper rendering of the gradations of the subject, but an exposure somewhere between these extremes, and Hurter and Driffield claimed that practically it indicated the beginning of the period of exposure in which correct gradation is secured.

The H. and D. numbers seen on boxes of plates and films are obtained by dividing a factor[17] of 34 by the value of the inertia. Thus a plate having an inertia of .54 will have an H. and D. speed of

$$\frac{34}{\cdot 54} = 63.$$

Variation of the Inertia.—While the precise significance of the inertia is somewhat clouded Hurter and Driffield could have found no other point so stable and so little susceptible to variation from which to calculate the sensitiveness of sensitive materials. Both Hurter and Driffield and also Sheppard and Mees have shown that, provided the plate does not contain free bromide, the value of the inertia is unaffected by variations in the time of development.[18] The value of the inertia is also unaffected by variation in the temperature of the developing solution (except with developers of very low reducing energy as hydrochinon) or by variations in the concentration, or composition, of the developer.[19] Hurter and Driffield also claimed that the inertia was constant for all reducing agents, but Mees and Sheppard were able to show that this was not strictly true. According to the results obtained by these investigators there are two general classes of sensitive material, one class gives practically identical values for the inertia regardless of the developing agent, while the other class gives a somewhat lower value with ferrous oxalate than with organic developers such as pyro, metol, etc.[20]

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[17] For the origin of the factor of 34 see Ferguson, *Phot. J.*, 1926, **66**, 514.

Although the inertia is constant with increasing time of development this is not true if the plate contains free bromide, or if the developing solution contains a soluble bromide. In this case there is a lateral shift of the curve towards the right with a consequent increase in the value of the inertia and lower sensitiveness. However if development is prolonged the restraining action of a soluble bromide on development becomes less and less and the inertia point gradually shifts to the left, finally reaching almost the same value as would have been secured had the developing solution been free from soluble bromide.[21] It is for this reason that all developers used for speed testing must not contain a soluble bromide, otherwise the speed of the plate will depend upon the degree of development and concordant readings will be difficult to obtain.

Effective Plate Speeds and H. and D. Speeds.—While the value of the work of Hurter and Driffield can hardly be over-estimated, the fact remains that the precise manner adopted by them for expressing the speed of a plate is not all that could be desired. At the present time the H. and D. system forms a convenient method of expressing the relative speeds of different sensitive materials under certain standardized conditions; it is not regarded, however, as an absolute or final expression of the effective speed of a given material.

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[18] H. and D. Memorial Volume, pp. 119–120. Mees and Sheppard, *Investigations*, p. 282. Later investigations, however, indicate that this statement is open to question and is not definitely settled as was formerly believed. See Sheppard, *Phot. J.*, 1926, **66**, 190.

[19] Mees and Sheppard, *Investigations*, p. 283, also 173.

[20] Mees and Sheppard, *Investigations*, p. 284.

[21] There is some question as regards this latter statement. Nietz in the *Theory of Development*, the latest authoritative work on the subject, was unable to confirm the previous statements of Hurter and Driffield and Mees and Sheppard. He remarks, however, that the results obtained were obscured in many cases by fog so that the conclusions may not be correct.

The H. and D. system largely ignores that portion of the characteristic curve generally referred to as the " foot "; or what Hurter and Driffield designated the period of underexposure, assuming it to be of little consequence in actual practice. According to the theories of Hurter and Driffield the foot of the curve will be employed in practice only where underexposure is unavoidable; under normal conditions when sufficient exposure can be given, the straight line portion, which they designated the period of correct exposure, will be employed. In general practice, however, the foot of the curve is not ignored; and the densities in the average negative which represent the shadow gradations do not lie on the straight line portion of the curve, where, according to the H. and D. system, they ought to be, but on the foot of the curve within the period of underexposure. Nor is this the case only when underexposure is unavoidable; as a matter of fact the foot of the curve is used for the shadows in general practice where plenty of time can be given. Investigation has shown that due to the limitations of positive printing materials the gradation in the shadows of the print correspond more closely to the visual impression of the subject when the foot of the curve is used than when the straight line period of correct exposure is employed.

Now, when the foot of the curve is used the actual speed of the plate is higher than that obtained by the H. and D. method which is based upon the use of the straight line portion of the curve. The *effective* speed of the plate, therefore, will depend on the extent to which it is possible to use the foot of the curve for the rendering of the shadows. This will depend upon the general shape of the characteristic curve. If the curve is of the type having a long straight-line portion and a very short foot the effective speed may be practically the same as the H. and D. speed, but if the curve is of the type having a long foot with a gentle slope then the effective speed may be much greater than the H. and D. speed determined in the usual manner by the extension of the straight line portion of the curve to the log E base.

Then there is the case of certain ultra-rapid plates, the curve of which shows practically two straight line portions; the long foot being practically a straight line but less steep than the second straight line portion which follows with increased exposure. In such cases, specification of speed in terms of the inertia is subject to many uncertainties. A portrait photographer, for example, may use the long foot of the curve almost exclusively. To him the plate may have a speed of say 600 H. and D. A press photographer who looks for greater contrast and density in his negatives, will use the steeper straight line portion of the curve and for him the same plate may have a speed of only 350 H. and D. The effective speed of a plate or film, therefore, depends upon the shape of the characteristic curve and the way in which the plate is used and it does not seem possible to express by a single number the absolute speed of a plate or film.[22]

Wedge Methods of Sensitometry.—Since the introduction of a simple method of manufacture by E. Goldberg in 1910, neutral tint wedges have been rather extensively used in photographic sensitometry.

Luther's method of obtaining the characteristic curve directly without troublesome calculations by means of graded neutral tint wedges is particularly ingenious. A square neutral-gray wedge of known gradation, increasing in density say from 0 to 6, or an intensity-range of transmitted light from 1 to 1,000,000, is taken and the plate to be examined is exposed behind this wedge to a standard light source and

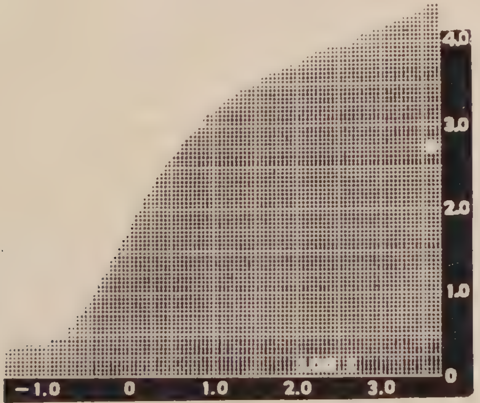

FIG. 133. Characteristic Curve Secured by Crossed Wedges

developed to a high contrast. When dry the negative is placed over the wedge used for exposure but at right angles to the same. When observed by transmitted light the characteristic curve is seen as a rather diffused line. To sharpen this line a print is made on a process plate which is developed to the limit in order to secure the maximum contrast and from this a print is made on vigorous gaslight paper, the boundary being reduced, locally if necessary, with a ferricyanide reducer in order to obtain a clear, sharp-cut line. The resulting curves may be scaled by impressing on the transparency the necessary scales, one of the unit lines of the log intensity scale being made coincident with a position line on the plate for which the effective exposure is known. The characteristic curve of a sensitive emulsion, as determined by the use of crossed wedges, is illustrated in Fig. 133.

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[22] For a method of expressing plate speeds in terms of the least minimum gradient of the curve, see Jones, *Proc. Seventh International Congress of Photography*, London, 1928, and Sheppard, *Phot. J.*, 1926, 66, 190.

The Perfect Negative.—We have now described the manner in which the sensitiveness of sensitive materials is determined and this was the primary object of the researches of Hurter and Driffield, who are largely responsible for the method which we have just described. The most valuable work resulting from the sensitometric investigations of Hurter and Driffield, however, has been the relation of the same to the reproduction of tonal values by the photographic process.

The function of photographic processes is to reproduce as faithfully as possible the shape and tones of natural objects. Accurate drawing is an optical concern and strictly speaking is only indirectly connected with photographic processes. The truthful reproduction of tone and gradation, however, is a function of the sensitive material and is thus distinctly a part of the photographic process. It is along these lines that the work of Hurter and Driffield has been the most fruitful, for they were the first to show the conditions governing the reproduction of tone by sensitive materials and its limitations.

A negative is said to be a perfect representation of the subject when its opacities are proportional to those parts of the subject which they represent. Thus with a subject having a range of intensities from 1 to 64 all negatives having the following opacity-ratios would be correct reproductions of the original, because in each case the relations between the various opacities and the corresponding portions of the subject are the same.

Light intensities of subject	1	2	4	8	16	32	64
Opacities	½	1	2	4	8	16	32
	¼	½	1	2	4	8	16
	⅛	¼	½	1	2	4	8

The relation between the light intensities, opacities and transparencies of a perfect negative may be evident from the following:

Light intensities of subject	1	2	4	8	16	32
Opacities	1	2	4	8	16	32
Transparencies	1	1/2	1/4	1/8	1/16	1/32

The Density-Exposure Relation and Correct Reproduction.—We have previously investigated the relation existing between exposure and density for the purposes of plate speed testing; we are now about to discover the relation which it has to the subject of tone reproduction.

When we perceive in nature a uniform transition from dark to light we may be sure that the intensity of the light increases more nearly in geometrical than in arithmetical progression, for in the latter case the transition from dark to light is abrupt and harsh. Consequently, since in most objects the light intensities increase in geometrical progression, the opacities of a negative which is a faithful reproduction of the subject must also increase in geometrical progression. Density we have previously defined (page 217) as the logarithm of the opacity, hence *with a series of opacities increasing in geometrical progression the densities increase in arithmetical progression.* This relation may perhaps be clearer from the following numerical example:

Light intensities of subject	1	2	4	8	16	32	64
Densities	1	2	3	4	5	6	7
Opacities	1	2	4	8	16	32	64

The mathematician calls each term of an arithmetic series which corresponds to any given term of a geometric series, the logarithm of that term; and the law which alone would produce absolutely true tones in photography would be expressed by saying that the quantity of silver reduced on the negative, or the density, is proportional to the logarithm of the light intensity.

From our discussion of the characteristic curve (page 222) it will be remembered that the curve is obtained by plotting density against the *logarithm* of the exposure. This curve is not a straight line, as would be the case if the densities increased in arithmetical order over the entire range of exposure, but on the contrary has an *f* shape which was divided into three portions, the lower concave portion, the straight line portion and the convex portion.

Attention has also been called to the fact that in the lower concave portion the densities increase on the same order as the exposures, or in geometrical progression. The light transmitted is therefore in arithmetical progression, producing a harsh, abrupt transition from dark to light which is characteristic of under exposure. This period is therefore termed the *period of under exposure.*

In the straight line portion of the curve it is evident that the densities increase as the logarithm of the exposure, or

$$dD/d \log_{10} E = \text{constant}.$$

Since this is the condition which has been shown to be essential to proper reproduction, this period is termed the *period of correct representation* or the *period of correct exposure.* In the convex portion of the curve the densities increase in less than arithmetical progression; consequently, the proper separation of the separate exposures is not secured and the result is flat and lifeless. This period is termed the *period of over exposure.*

The period of reversal is without significance so far as the subject of tone reproduction is concerned.

Latitude of Sensitive Materials.—The capacity of a given sensitive material in the matter of tone rendering is therefore determined entirely by the length of its straight line portion. It is in this respect that sensitive materials differ widely. Plates to be used for portraiture, and other work in which a long scale of tones must be accurately reproduced, must have a long straight line portion so that the whole range of light intensities can come within the straight line portion of the curve of the sensitive material. Plates for commercial and other work of this nature where greater contrast is required and where the subjects do not possess such a long range of light intensities do not have this long straight line portion with its accompanying power of exact reproduction.

The length of the straight line portion of the characteristic curve represents what is commonly termed the *latitude* of the sensitive material. *Latitude in exposure* depends upon two things:

1. Upon the extent of the straight line portion of the sensitive material.

2. The range of light intensities in the subject.

Let us suppose a sensitive material having a long straight line portion capable of rendering a range of exposures from 1–64 (Fig. 134). Now if we have a subject with a range of exposures from 1–16 (represented by the arrows) it will be evident that the exposure may be increased four times without forcing any of the tones into the period of over exposure. However, if the range of light intensities in the subject is increased to 1–32, then the exposure could be increased only twice without forcing some of the exposures beyond the straight line portion. In the first case the sensitive material would be said to have a latitude of exposure of 1–4; in the second case 1–2.

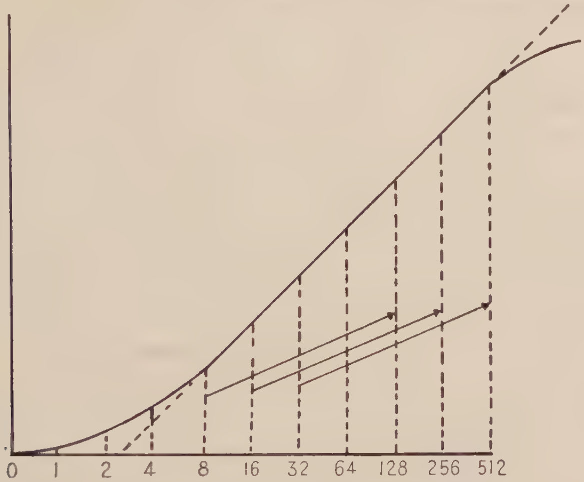

FIG. 134. Latitude and the Characteristic Curve

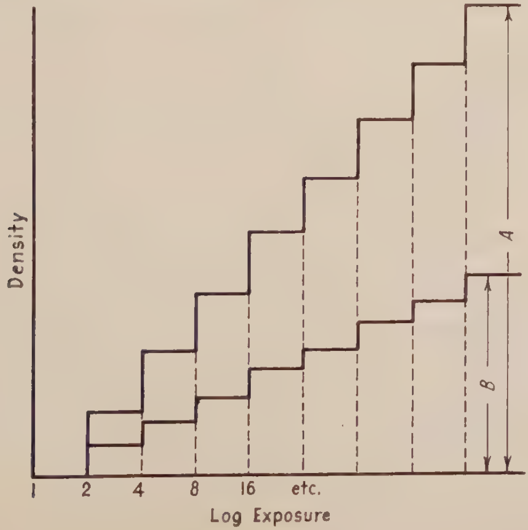

FIG. 135. Development and Constant Density Ratios

Hence the latitude in exposure possessed by a given sensitive material is a relative term depending upon the range of light intensities in the subject.

Development and the Reproduction of Contrast.—While correct exposure is absolutely necessary for correct rendering, it alone is not sufficient, for the time of development also plays a part. It is the function of exposure to secure the proper relationship between the *densities* and the light intensities which produced them. The densities are, however, only a half-way step towards the realization of a perfect negative. It will be remembered that it is the *opacities* which must be proportional to light intensities which produced them. While development is without effect on the relationship of the densities, it does affect very markedly the ratio of the opacities, so that it follows that development is a very important factor in securing correct reproduction.

Constant Density Ratios.—The effect of the time of development on a series of densities may perhaps be made clear with the aid of Fig. 135. The two series of gradations represent two sensitometric strips which have received identical exposure but different times of development. Series *A* we will assume to have received 4 minutes development; series *B* 2 minutes. The equal rise in the steps of each staircase indicates that the relationship of the densities is the same in both cases and consequently the density ratios are not altered by variation in the time of development. This is what is meant by the *law of constant density ratios,* which was first enunciated by Hurter and Driffield in 1890.[23]

In confirmation of the law of constant density ratios we reproduce the following experimental data from an investigation of Hurter and Driffield:

	Exposures			
	1	2	4	8
Density$_1$ (4″ development)	0.775	1.000	1.180	1.250
Ratio of densities D_1	1.0	1.29	1.52	1.61
Density$_2$ (12″ development)	1.260	1.660	1.96	2.08
Ratio of densities D_2	1.0	1.31	1.55	1.65
Ratio D_1/D_2	1.63	1.66	1.66	1.60

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[23] "Photo-chemical Investigations," *J. Soc. Chem. Ind.* (1890), 9.

Thus it is evident that, within the limits of experimental error, evidence supports the law of constant density ratios. Since the ratio of the densities is unaffected by the time of development, it is evident that the ratio is a function of the exposure and that unless the exposure has produced the proper relationship between the densities and the light-intensities which produced them correct reproduction is impossible.

An Important Difference.—But while the *density ratios* are unaltered by the time of development, the *opacity ratios* are, the effect of an increased time of development being to considerably increase the ratio of the opacities. Upon re-examination of the two staircases of Fig. 135 it will be observed that while the progression of the densities is the same in both cases, the amount by which the densities differ, indicated by the height of the individual steps, is considerable and that the total range of *A* is much greater than *B*. Numerical data, from an experiment of Hurter and Driffield, which shows how development affects the ratio of the opacities, without altering that of the densities, follows:

	1 Exposure C. M. S.	2 Density	3 Density ratio	4 Opacity	5 Opacity ratio
Strip 1, Developed 4″..........	1.25	.310	1.0	2.04	1.0
	2.5	.520	1.67	3.31	1.62
	5.0	.725	2.33	5.30	2.59
Strip 2, Developed 8″..........	1.25	.530	1.0	3.38	1.0
	2.5	.905	1.70	8.03	2.37
	5.0	1.235	2.33	17.18	5.08
Strip 3, Developed 12″.........	1.25	.695	1.0	4.95	1.0
	2.5	1.140	1.64	13.80	2.78
	5.0	1.625	2.33	42.17	8.51

It will be observed that all three strips received identical exposures, but varying times of development. Column 3 shows that the density ratios are practically identical in all three cases, indicating that the increased time of development is without effect on the density ratios. Column 5, however, shows that the opacity ratios have increased considerably with increased time of development. Thus in the first strip the ratio of the minimum and maximum opacities is 1–2.59; in the second strip the ratio is 1–5.08; while in the third strip the ratio has increased to 1–8.51.

Development and Contrast.—We now see clearly the relation between exposure and development and the part each plays in securing a faithful reproduction of the subject as it appears to our visual senses. Exposure is responsible for the proper relationship between the tones, while development determines the differences between the tones. The amount of this difference is determined solely by the duration of development and constitutes what is termed the *contrast*. Control in development is confined entirely to the length of time which the developer is allowed to act. The growth of no one density may be restrained or increased without affecting the others proportionately. Erroneous exposure cannot be corrected by any alteration whatsoever in development, for if the proper relationship between the densities has not been secured by giving the correct exposure, then no amount of development will supply that relationship which must exist between density and exposure for correct reproduction.

Thus there is one, and only one, time of development which will give a technically perfect negative. The proper time of development for a technically perfect negative is that time of development which is required to produce a series of *opacities* which are directly proportional to the light intensities which produced them.

In practice, however, owing to the differences in the properties of various printing media, it may be advisable either not to reach this exact proportionality or in other cases it may be advisable to exceed it in order that the visual appearance of the positive print may correctly reproduce the original subject. It must be remembered that the negative is only a means to an end. It is the positive print which is the final result and regulation of the contrast of the negative to meet the requirements of the printing medium is not only proper but necessary.

Gamma as a Measure of Contrast.—Hence we require not only a means of measuring contrast after it is obtained but also a means of calculating the time of development required to reach any given stage of contrast. For this purpose use can hardly be made of the opacities on account of the mathematical complexity which controls their growth and therefore it is common to express the degree of contrast in terms of densities and log exposures, the units of the characteristic curve. To the degree of contrast expressed in terms of density and log exposure, Hurter and Driffield gave the term *gamma* (γ) which has since been generally adopted.

Gamma is the ratio of the density range of the negative to the range of the logarithms of the exposures producing them. Or in other terms

$$\frac{\text{Difference in maximum and minimum densities of a given series}}{\text{Difference in the logarithms of the corresponding exposures}}$$

or again

$$\gamma = \frac{D_2 - D_1}{\log E_2 - \log E_1},$$

where D_1 and D_2 are the minimum and maximum densities of the corresponding exposures E_1 and E_2.

Aside from being an expression of the degree of contrast in the negative, gamma also expresses the relation between the contrast of the negative and the subject which it represents. If the value of gamma is less than one the contrast is less than that of the subject, while if it is more than one the contrast is greater than the subject, provided that in each case the range of exposures fall within the straight line portion of the characteristic curve. The application of gamma as a measure of contrast holds only within the period of correct exposure. Under-exposure produces the effect of high gamma, while over-exposure has the reverse effect, but in both cases the difference in the densities is not proportional to the difference in the logarithms of the exposures and gamma as a measure of contrast fails to have any real significance.

Gamma and the Characteristic Curve.—If we connect the various densities of the two staircases of Fig. 135 with a straight line, it is evident that the angle which this line makes with the log exposure base is greater the longer the time of development. In other words the longer the time of development, or the higher the value of gamma, the steeper the slope of the straight line portion to the base. The slope of the straight line portion of the curve, or the angle which it makes with the log exposure line, is thus a measure of the amount of difference between the densities, or, in other words, of gamma.

This relation may be expressed in a very simple manner by means of a little geometry applied to the characteristic curve.

By giving a plate two exposures denoted at *A* and *B* (Fig. 136) on the log exposure scale, we obtain densities denoted by the heights of the vertical lines *AC* and *BD*. The horizonal lines *OA* and *OB*, therefore, measure the log exposures in like terms.

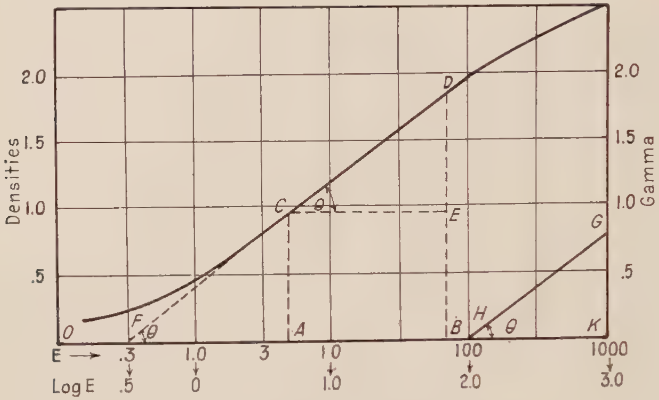

FIG. 136. The Geometry of Gamma. (Brown)

Now apply the formula which we have previously arrived at from our definition of gamma, that is:

$$\gamma = \frac{D_2 - D_1}{\log E_2 - \log E_1}.$$

In the diagram draw *CE* parallel to the log exposure base line *OB*.

$$\text{Then gamma} = \frac{BD - AC}{OB - OA} = \frac{DE}{AB} = \frac{DE}{CE}.$$

Now this ratio *DE*/*CE* is one way of measuring the angle *CDE* or θ (theta). It is the tangent of the angle θ (theta), the ratio of the side (in any right angle triangle) opposite one of the other angles to the side connecting this opposite side to the angle:

$$\text{the ratio } \frac{\text{perpendicular}}{\text{base}} \text{ of trigonometry.}$$

This tangent of the angle θ (theta), or tan θ, as it is called, is equal to gamma, for it is plain from the diagram that the angle *DCE* is equal to the angle *CFA*, which is the angle of the slope of the straight line portion of the characteristic curve.[24]

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[24] I am indebted to Mr. George E. Brown for the above method which is taken from his "Hurter and Driffield Doctrine" in the *British Journal of Photography*, 1921, 68, 374.

The Calculation of Gamma.—It would be possible to measure the angle and find the value of its tangent in the published tables but there is a much simpler way of finding the value of tan θ by using the chart itself.

From the point 100 on the log exposure scale draw a line (*HG* in Fig. 136) parallel to the straight line portion of the characteristic curve (*CD* in Fig. 136) until it intersects with a perpendicular drawn through the 1000 point on the log exposure scale (*G* in Fig. 136). It is clear that since *HG* is parallel to *CD* the angle *KHG* is also equal to θ and therefore tan *KHG* is equal to tan θ or gamma. Tan *KHG*, however, equals GK/HK which in turn equals $GK/1$ since the difference between the log of 100 (= 2) and the log of 1000 (= 3) is 1.

Therefore if we mark on the vertical line *KG* a scale which corresponds with that on the opposite side of the chart, the point where the parallel line from *H* meets the scale indicates the gamma without any calculation at all. This method of calculating gamma was devised by Hurter and Driffield.

A slightly different method but based upon the same mathematical principle is used by Mr. Alfred Watkins. A distance is measured off on the log exposure scale equal to 10 times the value of the inertia obtained by projecting the straight line portion of the curve until it intersects with the log exposure scale. At this point erect a perpendicular line to intersect with the characteristic curve. The density at the point of intersection is equal to gamma. Thus in Fig. 136 the value of the inertia is 0.3 and

$$10 \times 0.3 = 3.0.$$

Erecting at 3 a perpendicular to the log exposure scale it is found that this perpendicular intersects the characteristic curve at a density of about 0.8 and is identical with the value secured by the previous method.

The value of gamma may also be calculated from any two densities within the straight line portion of the curve from the formula

$$\gamma = \frac{D_2 - D_1}{\log E_2 - \log E_1}.$$

The graphical methods, however, are much more convenient.

Instruments have been devised by which gamma may be obtained without calculations or plotting of densities: consideration of these, however, is beyond the scope of this work.[25]

The time of development necessary to obtain any given gamma when the time of development for other values of gamma is known will be given later in the chapter on the theory of development.

Gamma Infinity.—The amount of contrast, and therefore the value of gamma, since gamma is the numerical expression of contrast, increases with the time of development up to a certain point; beyond this point no further increase occurs, in fact, after this stage has been reached, lengthened development *reduces* rather than increases the value of gamma owing to the intervention of fog, the effect of which is greater on the lower densities than on the higher. The maximum amount of contrast or, in other words, the highest gamma obtainable with any given material is termed *gamma infinity* (γ_∞).

The value of gamma infinity depends chiefly upon the sensitive material, although experimentally small variations are secured with different developing agents.[26] High speed emulsions for portrait work have a low gamma infinity as a high degree of contrast is never required in portrait work: in fact material tending to give a high gamma would be a disadvantage. In commercial, landscape and general exterior work greater contrast is required and sensitive materials made for these purposes are made to develop to higher values of gamma infinity than those made for portrait work. The greatest contrast of all is secured with plates of the process type as used for copying line work in black and white where absolutely clear lines together with a field of the greatest possible opacity is required.

Gamma infinity may be determined experimentally, but as it involves the measurement of very high densities and since these may be more or less affected by the fog produced on long development, the process is subject to large experimental errors and the values of gamma infinity are generally determined by calculation from lower values of gamma. It will be remembered that in exposing the sensitive material in the sensitometer two strips were exposed under identical conditions and that these strips were later developed under like conditions, the duration of development, however, varying as 1 : 2.

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[25] See: Watkins, *Phot. J.* (1912), **52**, 206; also *Photography, Its Principles and Applications.* Renwick, *Phot. J.* (1914), **54**, 163.

[26] Nietz, *Theory of Development,* p. 102.

A method of calculating gamma infinity from the values of two sensitometric strips developed so that

$$t_2 = 2t_1$$

was first worked out by Mees and Sheppard in 1903.[27] From certain mathematical data based upon the velocity of development they calculated the following expression of gamma infinity in terms of lower gamma:

$$\gamma_\infty = \frac{\gamma_1}{1 - e^{-kt}} = \frac{\gamma_2}{1 - e^{-kt_2}}.$$

This formula, however, is not so simple as that of Renwick:[28]

$$\gamma_\infty = \frac{(\gamma_1)^2}{(2\gamma_1) - \gamma_2}.$$

A graphical method of determining gamma infinity which avoids all calculation has recently been worked out by Renwick and will be found extremely convenient.[29]

General Reference Works

EDER—Systeme der Sensitometrie des Plaques Photographiques. (French translation by E. Belin, 1902.)
EDER AND VALENTA—Beitrage zur Photochemie.
FERGUSON—Hurter and Driffield Memorial Volume. With excellent bibliography to 1920.
LOBEL—Manuel de Sensitometrie.
MEES AND SHEPPARD—On the Theory of the Photographic Process.

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[27] *Phot. J.* (1903), **43**, 199.

[28] *Phot. J.*, 1911, **51**, 213.

[29] *Phot. J.*, 1923, **63**, 331. For two other methods see: Renwick, *Phot. J.*, 1914, **54**, 165–6. Krohn, *Phot. J.*, 1914, **54**, 166–7.

CHAPTER X

THE EXPOSURE OF THE SENSITIVE MATERIAL

The Problem.—The problem in the exposure of the sensitive material is to find that time of exposure which is necessary under the prevailing conditions of light, subject and diaphragm to produce for each tone in the subject a proportionate density in the negative, so that the densities representing the tones of the subject may all lie within the straight line portion of the characteristic curve.

There are four factors which determine the correct time of exposure:

1. The intensity of the light.
2. The subject.
3. The speed of the lens (or the diaphragm used).
4. The sensitiveness of the plate or film.

Light Intensity and Exposure.—The intensity of natural light is determined by the time of day and time of year, by disturbances in the atmosphere and by latitude.

Based upon investigations of Bunsen and Roscoe, Scott of Dublin in 1880 drew up a series of tables showing the variation in the intensity of daylight due to time of year, time of day and latitude.

Assuming equal conditions the table on page 241, therefore, indicates *relative* exposures for different seasons and latitudes.

The countries south of the equator have their maximum light value in December, instead of June, therefore, if the positions of the months in the above table are exactly transposed, the table will apply both to the Southern and Northern hemispheres.

Atmosphere.—If the intensity of sunlight was unaffected by the atmosphere and physical obstructions the simple table above would be an accurate guide to photographic exposures. But the intensity of sunlight is markedly affected by the presence of clouds or dust particles in the air. Clouds at times may increase the intensity of sunlight by reflection, but more often they decrease its intensity. Such alteration is extremely difficult to estimate except by chemical means

Variation in Exposure from Morning until Evening for Different Latitudes

By R. de B. Adamson, B.Sc.

British Journal Photographic Almanac

Latitude	North Hemisphere	Morning									South Hemisphere
		12	11	10	9	8	7	6	5	4	
60°	June	1	1	1	1½	1½	2	3	4	8	December
	May, July	1	1	1½	1½	1½	2	3	6	10	Jan., Nov.
	April, Aug.	1½	1½	1½	1½	2	3	6	—	—	Feb., Oct.
	Mar., Sept.	1½	1½	2	2	3	6	—	—	—	Mar., Sept.
	Feb., Oct.	3	3	3	6	—	—	—	—	—	April, Aug.
	Jan., Nov.	4	6	8	—	—	—	—	—	—	May, July
	December	6	8	—	—	—	—	—	—	—	June
55°	June	1	1	1	1	1½	2	3	4	—	December
	May, July	1	1	1	1½	1½	2	3	6	—	Jan., Nov.
	April, Aug.	1	1½	1½	1½	2	3	6	—	—	Feb., Oct.
	Mar., Sept.	1½	1½	1½	2	3	6	—	—	—	Mar., Sept.
	Feb., Oct.	2	2	3	4	8	—	—	—	—	April, Aug.
	Jan., Nov.	3	3	4	8	—	—	—	—	—	May, July
	December	4	4	6	—	—	—	—	—	—	June
50°	June	1	1	1	1	1½	2	3	6	—	December
	May, July	1	1	1	1½	1½	2	3	8	—	Jan., Nov.
	April, Aug.	1	1	1½	1½	2	3	6	—	—	Feb., Oct.
	Mar., Sept.	1½	1½	1½	1½	3	6	—	—	—	Mar., Sept.
	Feb., Oct.	2	2	2	3	6	—	—	—	—	April, Aug.
	Jan., Nov.	3	3	3	6	—	—	—	—	—	May, July
	December	3	4	6	—	—	—	—	—	—	June
40°	June	¾	¾	1	1	1½	2	3	—	—	December
	May, July	¾	1	1	1	1½	2	4	—	—	Jan., Nov.
	April, Aug.	1	1	1	1½	1½	3	6	—	—	Feb., Oct.
	Mar., Sept.	1	1	1½	1½	2	4	—	—	—	Mar., Sept.
	Feb., Oct.	1½	1½	1½	2	4	—	—	—	—	April, Aug.
	Jan., Nov.	1½	2	2	3	6	—	—	—	—	May, July
	December	2	2	3	4	8	—	—	—	—	June
30°	June	¾	¾	1	1	1½	2	4	—	—	December
	May, July	¾	¾	1	1	1½	2	6	—	—	Jan., Nov.
	April, Aug.	¾	1	1	1½	1½	3	8	—	—	Feb., Oct.
	Mar., Sept.	1	1	1	1½	2	4	—	—	—	Mar., Sept.
	Feb., Oct.	1	1	1½	1½	3	6	—	—	—	April, Aug.
	Jan., Nov.	1½	1½	1½	2	4	—	—	—	—	May, July
	December	1½	1½	1½	2	4	—	—	—	—	June
		12	1	2	3	4	5	6	7	8	
		Afternoon									

and although the eye after experience may be able to approximately determine its *visual* intensity, it cannot estimate its actinic intensity and it is this with which we are concerned. Towards evening, when the sun approaches the horizon, there is a marked decrease in the actinic power of the light, but the eye detects little, if any, difference and it is difficult to estimate exposures under these conditions. The following will give an idea of the relative intensity of light under different conditions of cloudiness, but is only approximate, as there are many degrees of cloudiness and the eye cannot readily estimate the extent to which the passage of actinic light is impeded by the same.

Intense light (best possible light)	1
Bright diffused light (sun behind clouds, but still bright)	1.5
Light clouds (shadows visible)	2
Heavy clouds (no shadows)	3
Very heavy clouds	4–5 or more

The Subject.—The majority of the subjects in general photography may be divided into six classes: Sea and Sky, Sea Views and Shipping, Open Landscape, Average Landscape, Outdoor Portraits, Interiors and Indoor Portraits.

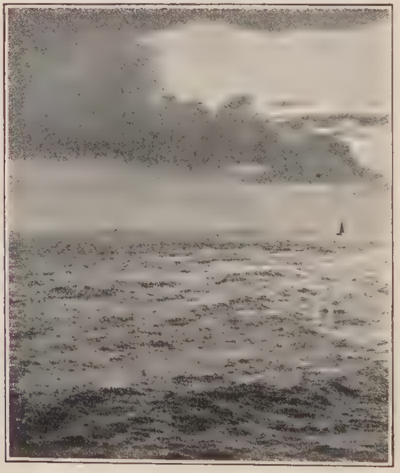


Fig. 137. Sea and Sky

Class I. Sea and Sky.—A subject, such as Fig. 137, which consists of sea and sky, receives the maximum amount of light, since there are no obstructions of any kind, while at the same time the amount and color of the reflected light is high, as few subjects reflect so large a proportion of the incident light as water the blue color of which is decidedly actinic. Unit Factor 1.

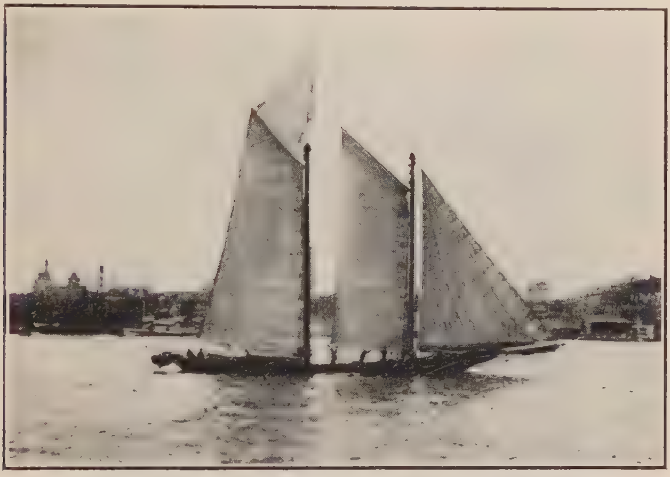


Fig. 138. Sea View and Shipping

Class II. Sea Views and Shipping.—Should the subject contain vessels within one hundred feet, the exposure would have to be increased on account of the near presence of a deeper shadow than common. Snow scenes, which contain no near dark objects and panoramic views, require about the same exposure as sea views with

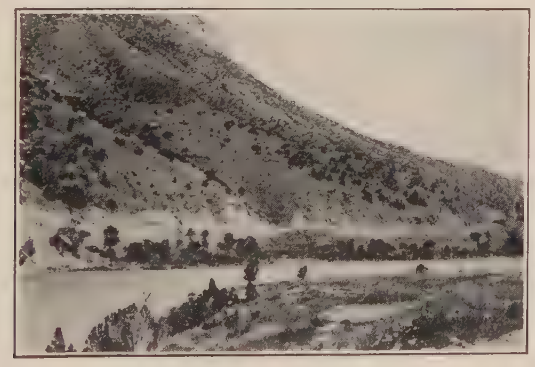


Fig. 139. Open Landscape

shipping. This class requires about double the exposure of the preceding. Unit Factor 2.

Class III. Open Landscape.—Open fields and landscapes containing no objects of importance within a hundred feet require about twice the exposure of the class above. Such a subject is shown in Fig. 139. Factor 4.

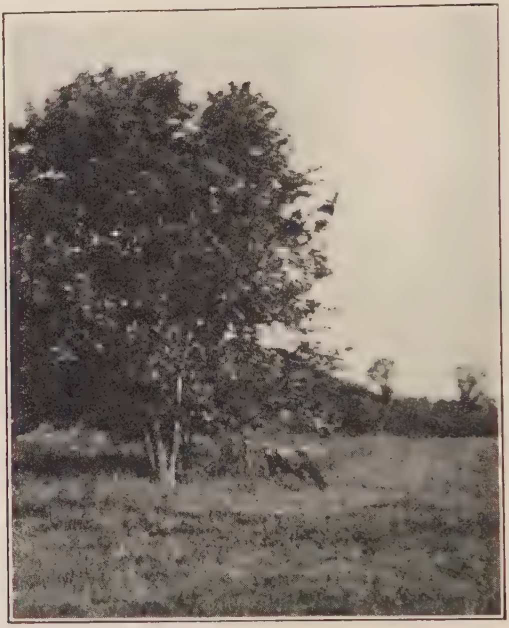


Fig. 140. Average Landscape

Class IV. Average Landscape.—If the figures in the above landscape should be brought nearer the camera than one hundred feet, the exposure would have to be increased as less light will be reflected from the subjects. Subjects in which the principal objects, whether persons, animals, or bushes, are about twenty-five feet from the camera fall into Class IV, illustrated in Fig. 140, and require about six times the exposure of Class I. Factor 6.

Street scenes require about the same exposure as Class IV, if the buildings are not close together or high, and if both sides are in sunlight. If the buildings are high, as in most business streets in the larger cities, the exposure must be increased.

Class V. Outdoor Portraits.—Portraits in the shade require from 8 to 10 times the exposure of Class I (*SEA AND SKY*). Conditions in this class of work vary to such extremes that it is difficult to fix a factor, but that given will serve as a guide.

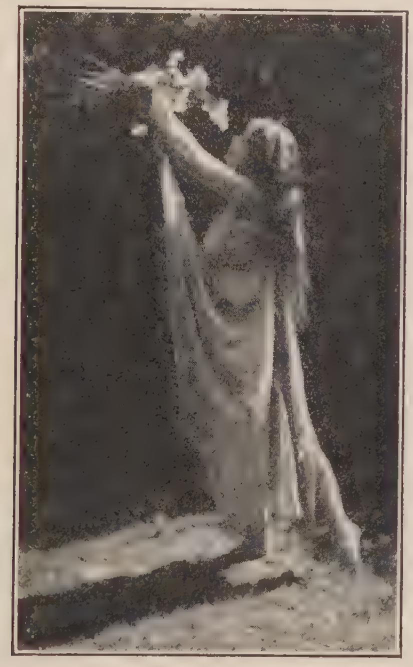


FIG. 141. Outdoor Portrait

Class VI. Interiors and Indoor Portraits.—For the same reason, it is almost impossible to fix a factor for indoor portraits or interiors. Perhaps the factors of fifteen and twenty respectively will fit average conditions.

Under equal conditions of light and color, exposure is unaffected by the distance of the subject and in a clear atmosphere, such as Switzerland or our own West, there are times when all objects beyond twenty-four times the focal length of the lens require the same exposure. In most parts of the country, however, there is a blue haze in the air which possesses high actinic value and consequently shortens the exposure required for distant objects.

Summarizing the factors for the different classes of subject we have:

Class I	Sea and sky	1
Class II	Sea views with shipping	2
Class III	Open landscapes	4
Class IV	Average landscape	6
Class V	Portraits in shade	8–10
Class VI	Indoor portraits	10–15
Class VII	Interiors	15–20

Speed of Plate.—Owing to the absence of any universal standard in sensitometric methods, the plate speeds of one manufacturer cannot be compared with those of another. At the present time the only reliable basis of speed comparison for the plates of different makers are the tables issued by the makers of the Watkins and the Wynne meters, the American Photography exposure tables and the Burroughs-Wellcome Handbook. These lists include practically all the plates on the market in English-speaking countries.

Table Showing Correspondence of Systems of Plate Speed Determination

By L. P. Clerc, in *Revue Francaise* from *British Journal of Photography*, 1922, 69, 200

Scheiner	Eder-Hecht	H. & D.	Watkins	Wynne	Relative
1	42	7	11	*F*/21	1
2	46	9	13	*F*/24	1.27
3	48	12	17	*F*/21	1.62
4	50	15	22	*F*/30	2.07
5	53	19	28	*F*/34	2.64
6	56	24	36	*F*/38	3.36
7	58	31	45	*F*/43	4.28
8	61	40	58	*F*/49	5.45
9	64	50	74	*F*/55	6.95
10	66	64	94	*F*/63	8.86
11	68	82	122	*F*/71	11.3
12	71	104	153	*F*/79	14.4
13	74	133	196	*F*/90	18.3
14	77	170	250	*F*/101	23.4
15	80	216	317	*F*/114	29.8
16	82	276	405	*F*/129	37.9
17	84	351	515	*F*/145	48.3
18	86	448	660	*F*/165	61.6
19	88	570	840	*F*/196	78.5
20	90	727	1065	*F*/209	100.0

Another disturbing factor which fortunately is seldom sufficient to cause serious trouble is the variation in speed of different batches of the same brand of plate.

While every possible means is taken to ensure the uniform speed of every batch of plates turned out, it is beyond human skill to secure complete uniformity and even with the best of attention and care to all processes, large variations in speed will now and then occur. Sometimes the variation may be as large as 50 per cent but this is unusual, although variations of 10 per cent are not uncommon. It would be a gain in accuracy and a distinct advantage to the practical worker to know the *actual* speed, secured by a laboratory test of each batch of emulsion, for each box of plates he uses.

Speed of Lens.—Under given conditions the time of exposure depends upon the intensity of the image produced by the lens. The optical conditions which determine the intensity of the image have been discussed already; here it is sufficient to state that in practice relative exposures are indicated with sufficient accuracy by relative apertures.

The variation in the intensity of the image with different objectives at the same relative aperture due to differences in the amount of light lost by absorption or reflection (see page 84) is in most cases within the limits of errors in exposure. The only time in which it would seem to be of practical consequence is in the case of some of the extremely rapid lenses used for cinematography where owing to the complex optical construction the intensity of the image is less than indicated by the relative aperture. The failure of photographic materials to obey the reciprocity law (page 213) is, with rapid plates used under ordinary conditions, so small as to be well within the latitude of the emulsion; only in the case of slow plates or films exposed in weak light does it become of consequence.

Determination of the Time of Exposure.—There are three methods in common use by which photographers determine the proper time to expose:

1. The empirical.
2. By the use of tables.
3. Exposure meters.

The first method calls for but the briefest comment. The so-called gift of exposure which many photographers claim to possess does not exist. The ability to estimate the time of exposure under given conditions by examination of the image on the ground-glass or other like means consists simply in the comparison of present conditions with past experiences and were it not for the remarkable latitude of sensitive materials such methods would end in failure. While it is possible for one as a result of extensive experience under certain conditions to estimate with a fair degree of accuracy the time of exposure under similar conditions, for most workers and especially for the beginner, the occasional worker or for one who works under varied conditions such methods are inaccurate and unreliable.

Reliable tables or exposure scales are much more satisfactory and if properly used will yield a high percentage of printable negatives, but here again a certain amount of judgment is needed, which is only obtained by experience, in order to properly classify the character of light, whether intense, bright, cloudy-bright, etc. While one gains ability in this respect with experience, even the trained eye is by no means an accurate judge of the actinic intensity of light, so that tables and scales are only another step toward the solution of the problem.

The only way to ensure success in exposure is by the use of exposure meters which actually measure the chemical activity of the light at the time of the exposure.

Exposure Meters.—There are two general types of exposure meters: (1) the *actinometer*, which measures the chemical strength of the light by the darkening of sensitized paper and (2) *visual meters*, which determine the strength of the light by photometric methods.

The two standard meters of the first class are the Watkins and the Wynne. Besides these there are several others, the Imperial, Photometer M. and V., Haka-Expometer, Metropose Michant, Steadman and Beck. The first named are made in watch form and both depend upon the darkening of sensitive paper to a standard tint which, however, differs in the two meters. In practice there is little to choose between them. The Wynne has a lighter standard tint and requires only one fourth the time to make a test of the light as the Watkins, but a separate quarter-tint dial can be obtained from the manufacturers of the latter. In the Watkins meter, the stop is placed against the plate speed number and therefore the scales do not need to be adjusted as long as the same plate, or stop, is in use. The Wynne indicates at the same time the exposure for all stops, but must be reset whenever there is a change in the light value. Properly used, there is no question as to the accuracy of either.

The rule for the use of the meter is to: Test the light in the shadiest part of the subject in which full detail is required. Therefore, if the subject is an open field, take the direct sunlight; if under the shade of trees, take the strength of the light where the subject is seated. Hold the meter to face the light that falls on the subject, not to face the camera nor the subject itself. In most cases, hold the instrument to face the sky but where the main light does not come from the sky, hold the meter so as to face the main source. The time required for the paper to reach the standard tint may be measured by a watch, by a pendulum or may be counted. All in all, the latter is to be preferred, but the worker must be able to count seconds accurately—a matter which is not difficult after a little practice with a watch. One of the best methods of timing seconds mentally is to repeat, audibly if necessary, some phrase which one can easily speak in a second, such as, for instance, one-thousand-and-one, one-thousand-and-two, etc. Most people's seconds are half-seconds. The watch is satisfactory, but with the pendulum it is difficult to watch both the meter and the bob at the same time. The stop-watch meters are accurate but expensive. It is easier to judge the proper matching of the two tints if the instrument is held at arm's length and the tint viewed through half-closed eyes. The important thing to observe, and the whole secret to the successful use of a meter, is the time required for the sensitive paper to reach the *darkness* of the standard tint. Color is not to be considered. Having found the actinometer time, as it is called, it remains to set the scales and read off the proper exposure. Full directions accompany each meter and the reader is referred to these for further details.

Should over or under exposure occur consistently when all of the above precautions have been taken, it may be corrected by a change in the speed of the plate. Thus, if over exposure occurs using plate speed 180 for Seed L Ortho plates, use a higher speed, say 250, while a lower plate speed, say 130 or 90, would be necessary if under exposure occurs with 180. Once the plate speed which gives the results desired has been found, it should be adhered to and used as the basis of all calculations. It is seldom necessary to make smaller alterations in plate speeds than 50 per cent. Thus a change from 90 to 100 would not be noticed and 130 might be used without noticeable alteration.

In the case of indoor portraits or interiors the time required for the determination of the actinometer time is lessened by the use of lighter tints for purposes of calculation. Thus with the Watkins meter the first visible darkening of the sensitive paper requires exactly 1/16 of the time necessary for the standard tint. One can, therefore, take the time in minutes or seconds for the sixteenth tint, multiplying this value by sixteen to obtain the full actinometer time. In the case of interiors or still life one may expose the plate and meter at the same time, the diaphragm employed being such that the camera exposure is equal to the actinometer exposure for either the sixteenth or quarter tint. Tables for this purpose are given in the instruction booklet accompanying each meter.

Corrections for Special Subjects.—For all ordinary subjects, as open landscapes, average landscape views, trees, portraits in shade, buildings, groups and interiors, no correction is necessary and the exposures indicated by the meter will be found about right. There are a few subjects, however, which require alterations in the meter reading because of their high actinic color and on account of exceptional reflecting power. The following table gives the proper alteration to be made for the more important of these exceptional subjects:

Sky or sea and sky	1/10 indicated exposure
Snow or glacier scenes, sea views with shipping, black and white prints	¼ indicated exposure
Open landscapes, lake views, river banks from the water, copying half-tone photos	½ indicated exposure
Very dark colored objects as old furniture and dark paintings in a non-actinic color	1½ indicated exposure

Visual Exposure Meters.—The actinometer measures the light falling on the subject; the visual meter the light reflected from the subject. In the earlier instruments of this type, such as the Heyde, the Ica Diaphot and the McMurty, the subject is viewed through an optical wedge, which for convenience is circular, and this is revolved past the eye until the detail in the shadows of the subject is barely visible. The proper exposure is then determined from the scales of the instrument at this setting. Meters of this type are convenient in use, have no sensitive paper to vary, and take into consideration the variations in the nature of the subject, but introduce other errors of their own.

In the first place, while the light sensitivity of the eye is for all normal eyes roughly about the same, the *form* sensitivity varies considerably. One person will thus be able to distinguish detail in a light so dim that another can see nothing clearly. Consequently, the point at which detail in the shadows seems to disappear will be different for the two individuals. Again, personal conceptions of what constitutes visibility of shadow detail varies with different people. The net result is that the personal equation plays a large part in the successful use of meters of this type and the photographer must first learn to use the meter and then apply a correction to its readings to account for his personal error in the use of the meter.

Secondly, it is well known that the eye is able to adjust itself to variations of light intensity over a fairly wide range. Thus on coming into a darkened room the eye soon adjusts itself to the weaker illumination and we shortly begin to see detail that was totally invisible when we entered the room. Consequently, the exposures indicated by the meter will not accurately represent the real difference in the intensity of the illumination on the two subjects. The result is that another correction factor has to be applied to the meter readings for interior work.

The major difficulties in the use of the detail obscuring types of visual meter have been cleverly overcome in the Justophot and the Cinophot of Dr. Mayer. In these a translucent figure is substituted for the detail of the subject, and the illumination on this figure is reduced by closing an iris diaphragm until the eye is no longer able to distinguish the numeral. Since the figure is either clearly visible, or not at all, the difficulty met with in the use of the older "detail-obscuring" type is entirely avoided.

Compensation for the variations introduced by the nature of the subject and the adaptability of the eye to the intensity of light is provided for by the use of figures of varying transparency according to the subject. Four separate figures are provided; the densest for open subjects in strong light; the second for overcast skies, or darker subjects; a third for heavy foliage, or brilliantly lit interiors, and a fourth for dense forest scenes and dark interiors. In the practical use of the meter, however, one does not bother about the proper figure to employ for a given subject and light condition but simply uses the darkest figure which can be seen with the iris diaphragm of the instrument fully open and the meter pointed at the subject.

Thus the difficulties formerly experienced in the use of exposure meters of the visual type have been almost completely eliminated in the newer design which represents undoubtedly the most practical instrument of its type ever constructed.

Visual photometers in which the intensity of the light reflected from the subject is measured by comparison with a source of known intensity furnished by a small electric light run from a battery represent a new class of exposure meter. There are two instruments of this type on the market: the Bell and Howell *Photo-meter* and the *Luxmètre Filmograph,* a French product. In the Bell and Howell instrument, the standard source of illumination is a small flashlight bulb operated by a single flashlight dry cell. The intensity of this light source is controlled by a rheostat. An image of the lamp is brought into the field of view adjacent to the subject by a simple optical device and by adjusting the rheostat, the intensity of the image of the standard source is reduced until it matches that of the subject. The proper time of exposure is then shown on the scales attached to the rheostat lever. With this instrument one may measure not only the general illumination over the whole subject, but when required the intensity of the light reflected from any portion of the subject. In many cases this is a decided advantage.

The *Luxmètre-Filmograph* is based upon the same general principles as the Bell and Howell Photo-meter, but a graduated wedge is used to reduce the illumination of the standard light source instead of a rheostat.

The use of a photo-electric cell instead of the eye for the measurement of the reflected light has been several times suggested and one or two exposure meters using photo-electric cells have been patented but thus far none have appeared on the market. It would seem that both size and weight as well as cost would hinder the widespread use of this type of meter.

GENERAL REFERENCE WORKS

BOURSAULT—Calcul du temps depose en Photographie.
CLEMENT—Methode practique pour determiner exactment le temps depose en photographie.
FRAPRIE—The Secret of Exposure.
Outdoor Exposures, Photo-Miniature No. 54.
Exposure Indoors, Photo-Miniature No. 157.
STEADMAN—Unit Photography and Actinometry.
WATKINS—Manual of Exposure and Development.
Correct Exposure—How to Secure It, Photo-Miniature No. 105.
VIDAL—Calcul des temps de pose et Tables photometriques.

CHAPTER XI

THE THEORY OF DEVELOPMENT

Introduction.—Like nearly all photo-chemical reactions, development is a complex and many-sided process. It is neither entirely chemical, nor physical, nor physico-chemical, but is a composite of all three. The first step in the process of development is the diffusion of the developing solution through the gelatine which carries the exposed silver halide grains in suspension. This constitutes what is termed the *invasion phase* and is entirely a matter of physics, being controlled by the physical laws of diffusion. Once the developing solution has reached the silver grain which has been acted on by light a reaction takes place in which the exposed silver halide is converted to metallic silver. This stage is chemical in character and may be termed the *reduction phase.* The silver so formed, we will find, is in solution and before the image is formed precipitation must take place. This is termed the *precipitation phase* and is chemical in character. The precipitation of silver results in a density and the difference between the densities produced by the action of varying intensities of light produces contrast. The growth of density and the growth of contrast are controlled by both the physical and the chemical phases of development and hence these are physico-chemical in character.

Thus we find that development may be broadly divided into three divisions:

1. The physical viewpoint.
2. The chemical viewpoint.
3. The physico-chemical viewpoint.

We will accordingly investigate the theory of the subject in this order.

The Invasion Phase.—The general properties of gelatine and the structure of the photographic emulsion were considered in the chapter on Emulsions, where we found that the photographic emulsion consists essentially of exceedingly minute particles of silver bromide held in colloidal suspension in gelatine. The exact structure of gelatine is still an unsettled matter, but it will suffice for our purposes if we represent by Fig. 142 the structure of the gelatine in which the grains of silver bromide are imbedded. The structure is of course very irregular, probably there is no definite structure, but the illustration will serve to illustrate the physical conditions of development. From an examination of this figure it will be observed that a jelly consists of a large number of cells which are intersected in all directions by passages. The cells and passages contain a weak solution of jelly while the walls consist of a very much stronger film of gelatine, the whole resembling a sponge filled with water. In *b* of the figure we have indicated by a black dot the grain of silver bromide in each of these cells of gelatine. Remembering that the individual grain is the limiting factor in development, we are now in a position to trace the course of a molecule of developing solution which is passing through the jelly on its way to the exposed grain of silver bromide.

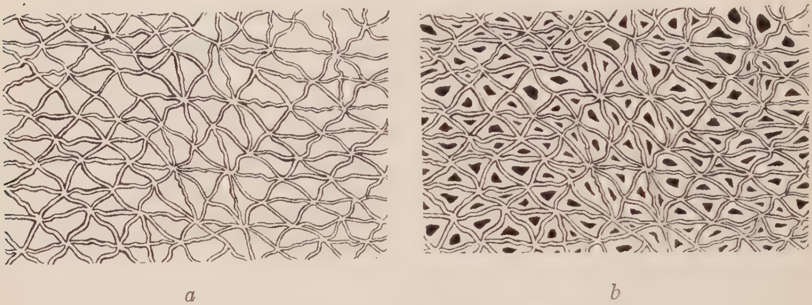


FIG. 142. The Invasion Phase of Development. (Mees)

Beginning at the surface of the film, a molecule of the developing solution rapidly diffuses through the passages and arrives at the cell wall. Here the gelatine is more resistant and the penetration is less rapid. Once the molecule has passed through the cell wall, chemical reaction proceeds immediately. The rapid diffusion of the developing solution through the passages is termed *macro-diffusion,* while the much slower penetration of the cell wall, which constitutes the second phase of the physical action in development, is termed *micro-diffusion.* The first phase is of exceedingly short duration and is complete within a very few seconds after the developer is applied. The second may require from several seconds to more than a minute. Both stages must be accomplished before the grain of exposed silver halide can be converted to metallic silver, and since this is necessary to produce the image, three stages of development, four in fact, have taken place when the image appears. Owing principally to the exhaustion of the developer as it penetrates the depth of the film, the exposed grains which lie near the surface are the first to be reduced, while those which are buried deeper within the film develop more slowly. Hence all three phases are taking place at the same time but in different parts of the film.

The Chemical Reaction within the Cell—the Reduction Phase.—Development is essentially a process of chemical reduction. According to the earliest theory of importance the process consisted in the reduction of the exposed silver bromide to metallic silver by the developing agent, the liberated bromine combining with the alkali to form an alkaline bromide. This reaction may be represented by the following equation in which D represents the developing agent:

$$AgBr + D\mathrm{Na} \rightarrow Ag + NaBr + D.$$

While apparently satisfactory, this theory really explains very little. For instance, it offers no explanation of the manner in which the developing agent is able to reduce the exposed silver halide to metallic silver. Accordingly later explanations are based on the theory of ions, which can explain more exactly the nature of the reaction which takes place. We know that chemical reaction can take place only in solution and the theory of solutions teaches us that a salt in solution is split up into the so-called *ions* which are atoms of the elements carrying an electric charge. Metallic or basic ions carry a positive (+) charge and are called *cations,* while acid ions carry a negative charge and are termed *anions.* Thus common salt (sodium chloride, NaCl) when dissolved in water is disassociated into the sodium cation and the chlorine anion. In the form of an equation this reads

$$NaCl \rightarrow Na^{+}\ Cl^{-}$$

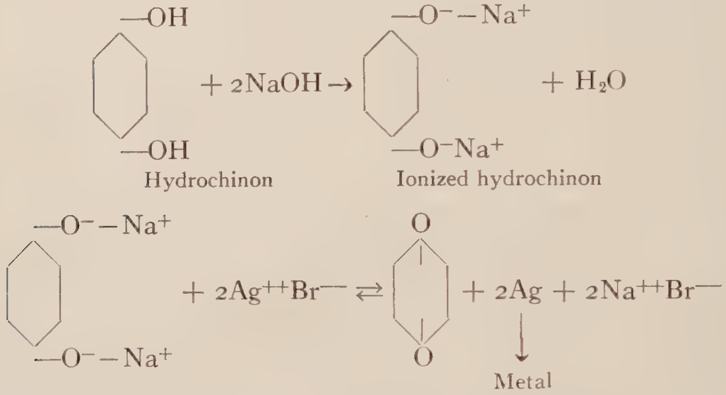
and in the case of AgBr this becomes

$$AgBr \rightarrow Ag^{+}\ Br^{-}.$$

A salt so disassociated is termed *ionized.*

According to the view most generally accepted in the scientific world of to-day, the first stage of the reduction phase consists of the disassociation and ionization of the exposed silver halide and the developing solution which has penetrated the cell wall and dissolved the silver bromide. As the two are both ionized there is an exchange of ions between the two. The silver cation receives an anion from the developer which is sufficient to remove its positive charge and neutralize it. It then ceases to be an ion and becomes metallic silver. The bromide anion is fixed in the form of a metallic or organic bromide according to the character of the developing agent. Owing to the exceedingly complex nature of the organic developing agents and to the secondary reactions which take place it is difficult to be more exact on this point. The only reducing agent whose action may be said to be fully understood is ferrous oxalate, although hydrochinon follows a fairly simple reaction when used without a sulphite. The reaction with hydrochinon is as follows:

$$AgBr \rightarrow Ag^{+} - Br^{-}$$



The ionized hydrochinon loses two anions which unite with and neutralize the two silver cations forming metallic silver, the two oxygen ions combine to form quinone and the bromine anion unites with the sodium cation to form sodium bromide. This completes the first stage of the reduction process and constitutes the *reduction phase.*

The Precipitation Phase.—We may now picture to ourselves the second phase of the chemical reaction within the cell, known as the *precipitation* phase. The metallic silver formed is in colloidal solution, and as the reaction proceeds more and more silver will be formed until the solution becomes saturated with respect to silver. The reaction must then stop, unless the silver is induced to precipitate. Some germ or nucleus is necessary in order to induce precipitation and the production of this nucleus is the function of the exposure. *The substance forming the latent image is thus the germ which induces the silver to deposit and by so doing produces the image.* "As silver is deposited, the concentration of silver solution within the cell is consequently lowered, and the reaction is increased, the deposited silver thus acting auto-catalytically (but only for the individual grain). The low solubility of silver is sufficient explanation of the localization of development to the individual grain."[1]

Investigation has shown that any trace of a nucleus is sufficient to render all of the silver bromide in that cell developable. Hence, provided the cell has complete access to the developing solution, there is no partial development of any cell; it is either completely developed or not at all.

Development as a Reversible Reaction.—The arrows in the above equation indicate that development from the chemical standpoint may be considered as a reversible reaction. This has been experimentally proven for the iron developer and for quinol. Mees and Sheppard[2] have shown that a solution of potassium ferri-oxalate and potassium bromide act on a developed negative to produce silver bromide. With hydrochinon, quinone and potassium bromide act on an exposed and developed plate to form quinol and silver bromide. This reverse action is largely prevented by the presence of the alkali and sulphites, always used with organic developers, so that the first oxidation product of the reducing agent is further oxidized by air and by the silver bromide and the reaction is then no longer reversible.

The Action of Sulphites, Soluble Bromides and Alkali in Organic Developing Solutions.—*The Action of Sulphites.*—Sodium sulphite is customarily added to all organic developing agents for the purpose of preserving the developer and preventing oxidation and consequent staining of the gelatine by the solution when in use. Notwithstanding its universal application its action is but little understood. There are four possible ways in which the sodium sulphite may aid in preventing oxidation of the developing solution:

1. The sulphite may be more readily oxidized than the developing agent.
2. The reverse may be true; but the sulphite may regenerate the developing agent.
3. The two may form a complex salt which is less subject to oxidation than either alone.
4. There may be no protective action, but only a division of oxidation, half of the oxygen going to the sulphite and half to the developer. This, as pointed out by Bancroft, would mean an actual though not theoretical decrease in the rate of oxidation.

The first we know definitely to be a fallacy, as many of the organic developing agents are more easily oxidized in solution than sodium sulphite. The experiments of Mees and Sheppard[3] with hydrochinon support the second explanation, but they were working under different conditions than those of actual practice. It is doubtful that any regeneration of the developing agent occurs with other developers than hydrochinon. There is at any rate no experimental evidence for any but hydrochinon at the present time. The third and fourth seem to be nearer the truth, for we know that hydrochinon and sulphite enter into combination and it is quite possible for the combination to be less subject to oxidation than either alone. But, like many other matters of everyday photographic practice, this is still an unsolved problem theoretically.

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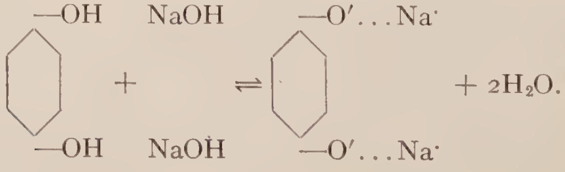
[1] Mees, *Phot. J.*, 1910, 50, 403.

[2] *Zeit. wiss. Phot.*, 1904, II, 5.

According to Rzymkowski,[4] the first stage in the oxidation of a developer containing sulphite by the oxygen of the air is the formation of a sulphate and a thiosulphuric acid derivative of the developing substance, $R\text{–}S\text{–}SO_3H$, which is then hydrolysed to the hypothetical compound R–SOH. The easily oxidizable SOH group is selectively converted to the sulphonic group SO_3H, and in this manner the active groups of the developing substance are protected from oxidation.[5]

The Action of Soluble Bromides.—The addition of a soluble bromide slows development by diminishing the degree of ionization of the silver bromide and by lowering the concentration of the silver cations which lowers the velocity with which the reaction proceeds to the saturation point. Hence the precipitation phase is delayed, because of the delay in reaching a saturated solution of silver within the cell. The influence of a soluble bromide is felt chiefly in the earlier stages of development.[6]

The Function of the Alkali.—According to the theory of development outlined in the preceding pages the reducing agents used for photographic development are considered as pseudo-acids having very small ionization constants but forming strongly dissociated salts. The function of the alkali is to assist in the ionization of the reducing agent and produce ionized salts, as in the case of hydrochinon



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[3] *Zeit. wiss. Phot.*, 1904, II, 7.

[4] *Phot. Ind.*, 1928, **26**, 627.

[5] See also Pinnow, *Phot. Rund.*, 1923, **60**, 27; *Zeit. Wiss. Phot.*, 1922, **22**, 72.

[6] See *Arch. wiss. Phot.*, 1900, II, 76. *Eder's Jahrbuch*, 1904.

The Physical Chemistry of the Developing Process

The Induction Period.—Even with the most energetic developers a short space of time elapses between the application of the developing solution and the first appearance of the image. This period is termed the *induction period.* The causes which produce this period are in general two: (1) the time required for the developer to penetrate the film, including both the macro and micro phases of diffusion referred to in a previous section, and (2) the time required to saturate the solution with silver in order that silver may be deposited and form a visible image. The actual duration of the induction period is controlled by the nature of the developing agent, metol and other energetic agents having a shorter period of induction than the lower energy developers as hydrochinon and glycin, the concentration of the developing solution, temperature and the presence of a soluble bromide. A soluble bromide such as potassium bromide materially increases the duration of the induction period, particularly with developers of low energy. Soluble iodides on the other hand have an accelerating effect and shorten the period of induction.[7]

The well-known Watkins method of factorial development is based upon the induction period. Watkins' principle is that for any developing agent the time required to produce the visible image is an accurate indication of the speed of development and is a certain definite fraction of the time necessary to reach any given stage of contrast. Any variation in concentration or temperature, etc., which would affect the time of development necessary to reach a given degree of contrast affects the time of appearance proportionately. In other words

$$T_d = WT_a,$$

where T is the time for density D, T_a the time of appearance and W a constant depending on the developer.

This statement is sufficiently near the truth to be of practical application but both theory and experiment show that this simple relation does not hold exactly. The Watkins method of factorial development will be referred to again in the chapter on The Technique of Development.

The Velocity of Development.—After the induction period is passed the growth of the image may be rapid or slow according to the conditions under which the process takes place. The principal factors which determine the rapidity of development are the same as those which influence the period of induction.

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[7] For a full explanation of this interesting reaction see Sheppard and Meyer. *Phot. J.*, 1920, 60, 12.

A knowledge of the velocity of development is essential to the calculation of the time required to reach a given stage of contrast (γ) and is most conveniently and accurately determined by the method of

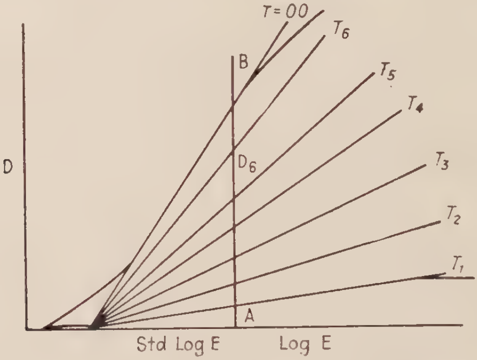

FIG. 143. Growth of Density with Time of Development. (Nietz)

Nietz.[8] It has been shown in the chapter on sensitometry that a series of plates exposed under identical conditions in a sensitometer and developed for varying times from t_1 to t_∞ produce a series of H. and D. curves the straight line portions of which meet in a point (Fig. 143). If we take any fixed exposure on the log exposure base

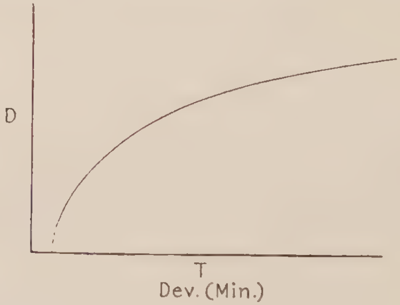

FIG. 144. Curve Showing Growth of Density with Time of Development (Nietz)

and erect a perpendicular line we have the information desired, i.e. the growth of density with development since the time of exposure for each of the densities is constant. By plotting D_1, D_2, etc., as a function of the time we get a curve of the exponential type (Fig. 144) which shows that density increases rapidly at first and then less and less rapidly as development proceeds until finally a point is reached where development apparently stops and there is no further increase either in density or contrast. This, it will be readily seen, is in agreement with conditions observed in everyday practice.

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[8] *Theory of Development,* p. 80.

The explanation of this progressive diminution in the velocity at which density increases is quite simple, although it is a difficult matter to find a mathematical expression which will cover all conditions.

After development for any length of time short of that required to produce the maximum density, we have three kinds of grains present:

A. Developed grains.
B. Developable but undeveloped grains.
C. Undevelopable grains.

The *A* grains thus represent the density already attained; the *A* and *B* grains together the maximum density which can be secured exclusive of fog. The *B* grains, therefore, are the only ones subject to development and as the reaction proceeds the number of *B* grains will become less and less until finally when all are developed the process must stop. Thus the density undeveloped at any time t will be $(D_\infty - D)$, where D is the density developed at any time t and D_∞ the maximum density. Supposing that the rate at which the developer reduces the exposed but undeveloped grains is a constant and independent of the number of grains (as is actually the case) and that the rate of diffusion remains unaltered, we can express the rate of development or dD/dt as

$$\frac{dD}{dt} = k(D_\infty - D),$$

where k is a constant determined by the rate at which the exposed grains are reduced by the developing agent. This formula fits the case fairly well with acid developers over a moderate range but wide variations are observed with most alkaline developers and other more complex equations have been suggested to account for the various factors involved. A comprehensive review of later work on the velocity of development and development velocity equations will be found in *The Theory of Development* by A. H. Nietz.

The Velocity Constant.—Now while the number of undeveloped grains constantly grows less and less as development proceeds, the rate at which the grains are attacked by the developing agent remains constant. Thus if we have a total of 100 developable grains present at the beginning of development and at the end of the first minute of development one half of this number or 50 have been reduced to the metallic state, then at the end of the second minute of development the developing agent will have reduced to metallic silver one half of the grains which remain or 25, and so on as the time of development is prolonged. In other words, the developing agent reduces to the metallic state a definite proportion of the remaining developable grains for each unit of time which it is allowed to act. This proportion is termed the *velocity constant of development.* It is usually denoted by k.

The velocity constant at the same temperature and with the same emulsion varies with the developer. It is different with different plates, being influenced by the conditions prevailing during the manufacture of the plates.

To determine the value of the velocity constant, k, we require to know the values of gamma for two sensitometric strips simultaneously exposed and developed for different times, of which one is double the other. The values of γ_1 and γ_2 having been found, k may be calculated from the following equation:[9]

$$k = \frac{I}{t_1} \log_e \frac{\gamma_1}{\gamma_2 - \gamma_1}.$$

The calculations are rendered simpler by the use of the following table worked out by Mees and Sheppard. To use this table divide γ_2 by γ_1 and against the value of this dividend in the table is the value of k for 5 minutes development. The value of k for any other time of development may be found by dividing 5 by the number of minutes development and multiplying by the value of k for 5 minutes. Thus if in a certain case the value for k is given in the tables as .215, k for 2 minutes development will be

$$k = \frac{5}{2} \times .215 = .538.$$

Calculation of the Time of Development for a Given Gamma.— We are now in a position to calculate the time of development required to obtain a given gamma with any particular developer. While in all sensitometric work it is desirable that plates be developed to a gamma equal to unity, in practical work it is often desirable, owing to the requirements of different printing mediums, to develop to lower or even higher values of gamma than unity. Thus negatives to be printed on carbon or platinum require to be developed to a higher gamma than those destined for use with developing-out papers. Then again it is usually desirable to develop different subjects to different gammas and consequently it is an advantage to be able to calculate the time of development to reach any gamma which may be desired. This is a comparatively simple matter if we have determined the gammas of two sensitometric strips simultaneously exposed and developed for different times so that one is double the other. These constants having been determined, the time of development required to reach any other

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[9] Mees and Sheppard, *Phot. J.*, 1903, **43**, 48; *Phot. J.*, 1904, **44**, 297.

k	$\frac{\gamma_2}{\gamma_1}$	Δ for Δ 0.001 in k	k	$\frac{\gamma_2}{\gamma_1}$	Δ for Δ 0.001 in k
0.005	1.977	0.0050	0.205	1.358	0.0018
0.010	1.952	0.0048	0.210	1.349	0.0016
0.015	1.928	0.0050	0.215	1.341	0.0018
0.020	1.903	0.0046	0.220	1.332	0.0016
0.025	1.880	0.0044	0.225	1.324	0.0016
0.030	1.858	0.0042	0.230	1.316	0.0016
0.035	1.837	0.0040	0.235	1.308	0.0014
0.040	1.817	0.0040	0.240	1.301	0.0014
0.045	1.797	0.0038	0.245	1.294	0.0016
0.050	1.778	0.0038	0.250	1.286	0.0016
0.055	1.759	0.0036	0.255	1.278	0.0014
0.060	1.741	0.0034	0.260	1.271	0.0014
0.065	1.724	0.0034	0.265	1.264	0.0014
0.070	1.717	0.0032	0.270	1.257	0.0012
0.075	1.691	0.0032	0.275	1.251	0.0012
0.080	1.675	0.0030	0.280	1.245	0.0012
0.085	1.660	0.0032	0.285	1.239	0.0012
0.090	1.644	0.0032	0.290	1.233	0.0012
0.095	1.628	0.0032	0.295	1.227	0.0012
0.100	1.612	0.0032	0.300	1.221	0.0010
0.105	1.596	0.0032	0.305	1.216	0.0012
0.110	1.580	0.0030	0.310	1.210	0.0010
0.115	1.565	0.0028	0.315	1.205	0.0010
0.120	1.551	0.0028	0.320	1.200	0.0010
0.125	1.537	0.0028	0.325	1.195	0.0008
0.130	1.523	0.0026	0.330	1.191	0.0010
0.135	1.510	0.0028	0.335	1.186	0.0008
0.140	1.496	0.0024	0.340	1.182	0.0008
0.145	1.484	0.0024	0.345	1.178	0.0008
0.150	1.472	0.0024	0.350	1.174	0.0010
0.155	1.460	0.0024	0.355	1.169	0.0008
0.160	1.448	0.0022	0.360	1.165	0.0008
0.165	1.437	0.0022	0.365	1.161	0.0008
0.170	1.426	0.0022	0.370	1.157	0.0006
0.175	1.415	0.0020	0.375	1.154	0.0008
0.180	1.405	0.0018	0.380	1.150	0.0006
0.185	1.396	0.0018	0.385	1.147	0.0008
0.190	1.387	0.0020	0.390	1.143	0.0008
0.195	1.377	0.0018	0.395	1.139	0.0006
0.200	1.368	0.0020	0.400	1.136	—

gamma may be found either by the graphical method of Hurter and Driffield[10] or that of Mees and Sheppard.[11]

The graphical method of Hurter and Driffield can be most simply explained by an example. Suppose γ_1 to be 0.82 and γ_2 to be 1.36. Take an ordinary H. and D. chart, such as used for plotting the characteristic curve, and call the base line divisions " Minutes of Developments " and the ordinates " Gammas ": then there are three points through which a curve may be drawn—0, 0.82 and 1.36. Suppose γ_1 (0.82) to have been produced by three minutes development and γ_2 (1.36) with six minutes; then γ_1 (0.82) is plotted on the 3 minute line and γ_2 on the 6 minute line. A curve is then drawn through these points and zero. Then the time of development for any desired gamma may be obtained by drawing a horizontal line from the left-hand scale until it cuts the curve and dropping a perpendicular from the point of intersection to the base. In the example shown the times required to reach gammas of 0.80, 1 and 1.30 are found to be 2.80, 3.75 and 5.75 minutes respectively.

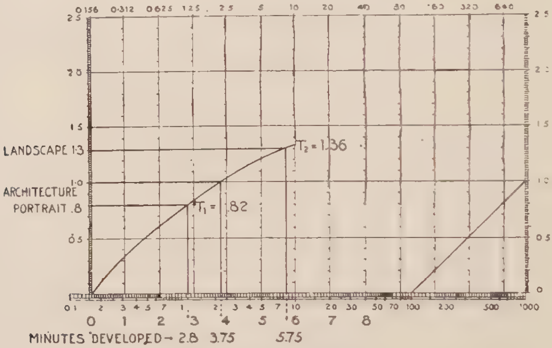

FIG. 145. H. and D. Method for Calculating the Time of Development for Given Gamma

For the second method as developed by Mees and Sheppard the values of gamma infinity (γ_∞) and the velocity constant of development (k) require to be known. Methods of calculating these constants have already been given: for the former on page 239 and the latter on page 262.

The values of these constants having been calculated for the case in hand, the time of development for any desired gamma may be obtained from the equation

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[10] Hurter and Driffield, *On the Control of the Development Factor. Phot. J.*, 1903, 43, 16.

[11] Mees and Sheppard, *Phot. J.*, 1903, 43, 48, 199.

$$\gamma_t = \gamma_\infty(I - e^{-kt}).$$

The actual calculations are rendered quite simple by the use of the tables (page 266) worked out by Drs. Mees and Sheppard for values of $(I - e^{-kt})$ and corresponding values of kt.[12]

From the above

$$\frac{\gamma_t}{\gamma_\infty} = (I - e^{-kt})$$

or

$$\frac{\text{Gamma required}}{\text{Gamma infinity}} = (I - e^{-kt}).$$

Therefore to obtain the time of development for a given gamma, divide the required gamma by the gamma infinity of the plate. In the second column of the tables find the nearest lower value of $(I - e^{-kt})$ corresponding to the dividend. Opposite this in the first column of the tables will be found the value of kt corresponding to that obtained for $(I - e^{-kt})$. Divide the value of kt as given by the value of k, as previously found by calculation, and the result is the time of development required to attain the desired gamma.

For example:

Gamma infinity = 1.6,
Velocity constant = .15,
Gamma required = 0.8.

Then

$$\frac{0.8}{1.6} = .5 = (I - e^{-kt}).$$

The nearest value of $(I - e^{-kt})$ in the tables which corresponds to .5 is .5034, corresponding to a kt of .700. Dividing this by the velocity constant (k) .15 we obtain 4.7 minutes, or 4 minutes and 42 seconds, which is the time of development for a gamma of 0.80.

Effect of Temperature on Development.—In common with nearly all chemical reactions, the rate of development is considerably influenced by temperature. The effect of temperature on the time of development was first studied quantitatively by Houdaille in 1903[13] whose work was followed up with a more complete investigation by

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[12] *Phot. J.*, 1904, **54**, 297–8.

[13] *Bull. Soc. Franc. Phot.*, 1903, **19**, 256.

TABLE OF CORRESPONDING VALUES OF kt AND $1 - e^{-kt}$ FOR DETERMINATION OF TIME OF DEVELOPMENT FOR REQUIRED GAMMA OF PLATE OF GIVEN k AND γ^{∞}
(Mees and Sheppard, *Photographic Journal*, November, 1904, page 297)

kt	$1 - e^{-kt}$	diff. for .01 kt	kt	$1 - e^{-kt}$	diff. for .01 kt
.000	.000	.0095	1.200	.6988	.0029
.025	.02		1.225	.7059	
.050	.046		1.250	.7131	
.075	.073		1.275	.7203	
.100	.0952	.0086	1.300	.7275	.0026
.125	.1174		1.325	.7339	
.150	.1387		1.350	.7403	
.175	.1600		1.375	.7469	
.200	.1813	.0077	1.400	.7534	.0024
.225	.2082		1.425	.7592	
.250	.2252		1.450	.7651	
.275	.2422		1.475	.7710	
.300	.2592	.0071	1.500	.7769	.0022
.325	.2769		1.525	.7822	
.350	.2945		1.550	.7875	
.375	.3121		1.575	.7928	
.400	.3297	.0064	1.600	.7981	.0021
.425	.3458		1.625	.8029	
.450	.3617		1.650	.8077	
.475	.3776		1.675	.8125	
.500	.3935	.0057	1.700	.8173	.0017
.525	.4085		1.725	.8215	
.550	.4234		1.750	.8259	
.575	.4373		1.775	.8303	
.600	.4512	.0052	1.800	.8345	.0016
.625	.4641		1.825	.8387	
.650	.4772		1.850	.8426	
.675	.4903		1.875	.8465	
.700	.5034	.0047	1.900	.8504	.0014
.725	.5138		1.925	.8539	
.750	.5281		1.950	.8575	
.775	.5394		1.975	.8611	
.800	.5507	.0042	2.000	.8647	.0013
.825	.5613		2.025	.8680	
.850	.5714		2.050	.8712	
.875	.5827		2.075	.8744	
.900	.5934	.0038	2.100	.8776	.0012
.925	.6031		2.125	.8805	
.950	.6218		2.150	.8834	
.975	.6225		2.175	.8863	
1.000	.6322	.0034	2.200	.8892	.00105
1.025	.6485		2.225	.8919	
1.050	.6547		2.250	.8945	
1.075	.6609		2.275	.8971	
1.100	.6671	.0032	2.300	.8997	.00096
1.125	.6741		2.325	.9021	
1.150	.6830		2.350	.9045	
1.175	.6909		2.375	.9069	

TABLE OF CORRESPONDING VALUES OF kt AND $1 - e^{-kt}$ FOR DETERMINATION OF TIME OF DEVELOPMENT FOR REQUIRED GAMMA OF PLATE OF GIVEN k AND γ^{∞}
(Mees and Sheppard, *Photographic Journal*, November, 1904, page 297)

(Continuation of page 266)

kt	$1 - e^{-kt}$	diff. for .01 kt
2.400	.9093	.00086
2.425	.9113	
2.450	.9135	
2.475	.9157	
2.500	.9179	.00078
2.525	.9197	
2.550	.9217	
2.575	.9237	
2.600	.9257	.00071
2.625	.9274	
2.650	.9292	
2.675	.9310	
2.700	.9328	.00064
2.725	.9344	
2.750	.9360	
2.775	.9376	
2.800	.9392	.00058
2.825	.9408	
2.850	.9412	
2.875	.9426	
2.900	.9450	.00052
2.925	.9463	
2.950	.9476	
2.975	.9489	
3.000	.9502	.00047
3.025	.9513	
3.050	.9525	
3.075	.9537	
3.100	.9549	.00043
3.125	.9559	
3.150	.9570	
3.175	.9581	
3.200	.9592	.00039
3.225	.9601	
3.250	.9611	
3.275	.9621	
3.300	.9631	.00036
3.325	.9639	
3.350	.9648	
3.375	.9657	
3.400	.9666	.00032
3.425	.9674	
3.450	.9682	
3.475	.9690	
3.500	.9698	.00029
3.525	.9706	
3.550	.9713	
3.575	.9720	
3.600	.9727	.00026
3.625	.9732	
3.650	.9739	
3.675	.9746	
3.700	.9753	.00023
3.725	.9758	
3.750	.9764	
3.775	.9770	
3.800	.9776	.00022
3.825	.9780	
3.850	.9786	
3.875	.9792	
3.900	.9798	.00019
3.950	.9807	
3.975	.9812	
4.000	.9817	

Ferguson and Howard, Alfred Watkins and Mees and Sheppard.[14] The ratio of the velocity constant, k, for any two temperatures is a measure of the effect of temperature on the velocity of development within this particular range and for that particular developing agent and is termed the temperature coefficient of development (T.C.). The range of temperature chosen in practice is 10° C. (18° F.) so that the expression for the temperature coefficient becomes

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[14] Ferguson and Howard, *Phot. J.*, 1905, **45**, 118. Ferguson, *Phot. J.*, 1906, **46**, 182. Mees and Sheppard, *Investigations.* Sheppard, *J. Chem. Soc.* (London), March, 1906. Ferguson, *Phot. J.*, 1910, **50**, 412. Mees, *Phot. J.*, 1910, **50**, 410. Watkins, *Phot. J.*, 1910, **50**, 411. Watkins, *Phot. J.*, 1909, **49**, 367.

$$kt^\circ\ \text{C.}/kt\ 10^\circ\ \text{C.}$$

The temperature coefficients of a few of the more common developing agents are as follows:

Pyro-soda without bromide	1.5
Pyro-soda with bromide	1.9
Rodinal, azol, certinal, etc.	1.9
Metol-quinol (no bromide)	1.9
Glycin	2.3
Rytol	2.2
Hydrochinon	2.25–2.4

As a general rule the temperature coefficient appears to be a characteristic of the developing agent, being for the most part unaltered by changes in the proportion of alkali to the developing agent, or by dilution, but it is much higher when bromide is used.

Mees and Sheppard have shown that there is also a variation in the temperature coefficient with different plates, so that a calculated T.C. for a given developer will not necessarily hold if a change is made to another brand of plates. The temperature coefficient is approximately constant, however, for different batches of the same plate.

With certain developing agents of low energy, such as hydrochinon, low temperature not only slows development but has an action similar to that of a soluble bromide at normal temperature, i.e. the inertia is lowered and the lower tones retarded.

Calculating the Temperature Coefficient.—As we have already seen, the time of appearance of the image is an indication of the velocity of development, hence we may calculate the effect of temperature on the rate of development with a given developing agent from the difference in the time of appearance of the image at two different temperatures. A plate is exposed and then divided into two pieces (or two identical exposures made). One of these is developed at any convenient temperature and the time of appearance noted. The other is developed at a temperature several degrees higher or lower; 10° C. (18° F.) being a convenient difference. The time of appearance at this temperature is noted.

We now have the time of appearance at two different temperatures and from this the temperature coefficient may be calculated by the following formula:

$$\frac{(\log T_a - \log t_a) \times 10}{T^\circ - t^\circ} = \text{log of T.C. for } 10^\circ \text{ C.}$$

In other words, the difference in the logarithms of the two times of appearance, multiplied by 10 and divided by the difference in degrees Centigrade of the two respective temperatures, is equal to the logarithm of the T.C.[15]

Thus if the times of appearance are 30 and 20 seconds at 17.5° C. (63° F.) and 25° C. (77° F.) respectively, we have

$$\begin{array}{lll}
\log 30 & = & \left.\begin{array}{l} 1.4771 \\ 1.3010 \end{array}\right\} \text{from log tables.} \\
\log 20 & = & \\
\hline
\text{Difference} & = & .1761 \\
\times\ 10 & & \quad\ 10 \\
\hline
 & = & 1.761 \\
\div\ 7.5 & = & .2348 \\
 & = & \text{log of } 1.72 = \text{temperature coefficient.}
\end{array}$$

A very ingenious graphical method devised by Mr. Alfred Watkins is even simpler and avoids all calculations whatsoever. The starting point on which his method is based is the fact that the time of development required to produce an equal gamma increases in logarithmic proportion while the temperature increases arithmetically. The times of appearance having been found for two different temperatures, a slip of paper is laid on the log scale of Fig. 146 and the times of appearance laid off against the corresponding values of the log scale. Beneath the marks are placed the respective temperatures. This slip of paper is then laid on the fan-shaped diagram and adjusted so that the two marks cut the lines of the two temperatures, the edge of the paper falling along one of the horizonal lines. The point where the paper slip intersects the radial temperature lines is marked with the proper temperature coefficient.[16]

As a result of extensive research, Watkins gives the following T.C. for several common developing agents:

Pyro-soda (Watkins thermo formula), no bromide	1.5
Pyro-soda (Watkins thermo formula), with bromide	1.9

[15] Ferguson, *Phot. J.*, 1910, **50**, 414; see also *Phot. J.*, 1906, **46**, 182.

[16] For other methods see Ferguson and Howard, *Phot. J.*, 1906, **46**, 182.

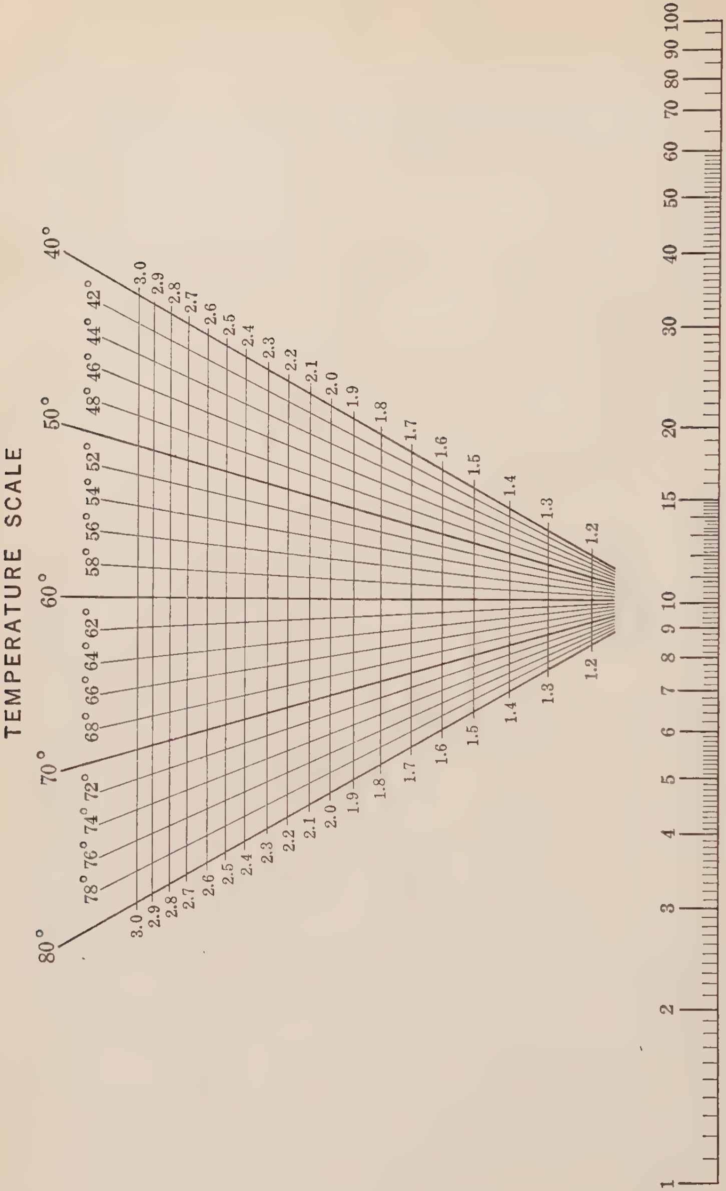

Fig. 146. Watkins Method of Calculating the T.C.

Pyro-soda (Hurter and Driffield formula)	1.48
Pyro-soda (Kodak powders)	1.9
Pyro-soda (Ilford formula)	2.04
Rodinal (also azol, victol and certinal)	1.9
Metol-hydrochinone (Watkins thermo formula)	1.9
Glycin	2.3
Hydrochinon	1.4 –2.25
(Sheppard and Mees) find	2.20–2.80
Ortol	2.06

Time of Development at Various Temperatures.—The time of development required to reach any given gamma and the T.C. for the same plate and developer having been obtained, the time of development at various temperatures is very easily found. Place the edge of a sheet of paper on the horizontal line corresponding to the T.C. of the developer and mark off the points of intersection with the temperature lines. Transfer this paper to the log scale, placing opposite the time of development in minutes or minutes and a fraction, the corresponding temperature at which the examination was made. This having been done the times of development at other temperatures necessary to reach the same gamma may be written down directly from the log scale.[17]

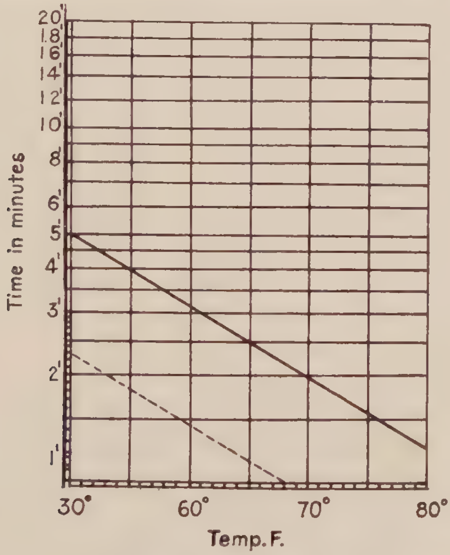

FIG. 147. Stokes Time Development Chart

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[17] This simple graphical method of drawing up a table for the time of development at various temperatures was first indicated by Mr. Alfred Watkins.

There is, however, no actual necessity for knowing the temperature coefficient in order to determine the time of development for various temperatures. Since the time of development for a given gamma progresses logarithmically as the temperature progresses arithmetically, if the time of development at two different temperatures is known, a straight line drawn through these two points when plotted on a log scale of times of development as ordinates against an even division scale of temperatures as abscissæ (Fig. 147) will indicate, for all practical purposes, the time of development at all intermediate points. This method is due to Mr. W. B. Stokes.[18]

The Action of Soluble Bromides in Development.—The customary addition of a certain amount of soluble bromide, which is nearly always potassium bromide, to a developing solution for the purpose of preventing " fog " materially affects the normal course of development.

For an unbromided developer the inertia is constant with increasing times of development, but this is not true in the case of a developer containing a soluble bromide in which case at the same degree of development there is a lateral shift of the curve to the right. This is illustrated in Fig. 148[19] where the solid lines represent the curves of the unbromided developer for three different degrees of development and the dotted lines the curves of the bromided developer for similar degrees of development. It is evident that if the curves of the bromided developer are produced below the log E base they will meet in a common point. As the concentration of bromide is increased

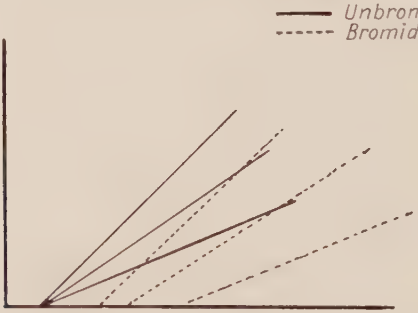

Fig. 148. Effect of a Soluble Bromide in the Developing Solution on the Plate Curve

this point of intersection moves slowly downward as shown in Fig. 149. The amount of the downward shift, termed the *density depression,* produced with a given concentration of bromide, is dependent upon the developing agent, being in general greater with low energy developers as hydrochinon than with those of greater energy such as paraminophenol and metol.

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[18] *Brit. J. Phot.*, 1921, **68**, 97.

[19] Sheppard, *Photography as a Scientific Implement*, p. 151.

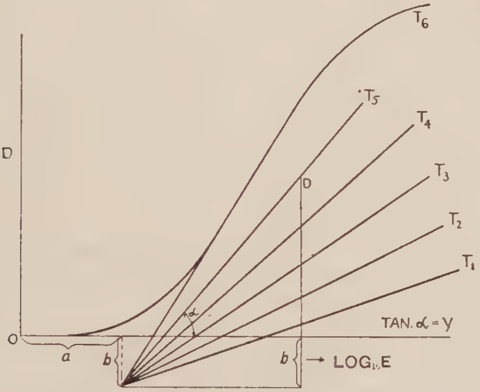

Fig. 149. Density Depression with a Soluble Bromide. (Nietz)

Bromide is without effect on the velocity constant k,[20] and investigation shows that its effect on the general velocity of development is felt chiefly during the earlier stages; the induction period and that immediately following.

Perhaps an even more readily comprehensible method of presenting

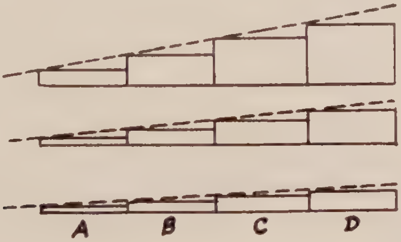

Fig. 150. Effect of Soluble Bromide on the Densities. (Watkins)

the action of a soluble bromide in development is that adopted by Watkins in the *Watkins Manual.* Fig. 150 represents a subject of four gradations for a given degree of development in an unbromided developer. The lower illustration represents the same exposure developed to the same stage in a bromided developer. It will be observed that, while the contrasts of both are equal, the action of bromide has reduced the tones considerably and this depression is more noticeable in the lower tones than the higher. In fact the addition of bromide has prevented the lowest tone from appearing at all. The effect of bromide is to actually reduce the speed of the plate. As the time of development is increased and a higher gamma is reached, the lower tones will develop out, so that in order to restrain the development of the shadow detail in over exposed plates development must be completed before the bromide has lost its restraining action. The use of bromide for this purpose, however, falsifies the gradation of the negative.

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[20] Nietz, *Theory of Development,* pp. 124, 170.

Theoretically gamma infinity is unaffected by the reasonable addition of bromide, but in practice, owing to the absence of fog, the printing contrast of a negative developed to the same gamma may be higher for the bromided than for the unbromided developer.

The restraining action of bromide is greater on fog than on the image, hence, even in cases of underexposure, a small amount of bromide may be advisable in order to prevent the appearance of fog due to development being forced beyond the usual limits in order to secure all possible shadow detail.

The Relative Reducing Energy of Developing Agents.—The effect of a soluble bromide at the same concentration varies with the developing agent but is constant and characteristic of that particular agent. Use was made of this property by Sheppard and Mees to compare different developing agents as to their relative reducing or developing energy known as the *reduction potential.* For a given concentration of bromide under fixed conditions the depression of density will be dependent upon the ability of the developer to overcome the resistance of the bromide. Developing agents of greater energy will require larger amounts of bromide to produce the same depression of density than those of lower energy; hence the concentration of bromide required to produce a given density depression will be in direct proportion to the energy of the developing agent.[21]

Taking the bromide concentration required to produce a given depression of density as unity, Nietz obtained the following scale representing the relative energies of the more common developing agents:

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[21] See Sheppard and Mees, *Investigations,* p. 188. Nietz, *Theory of Development.*

Ferrous oxalate	0.3	
p-phenylene diamine hydrochloride (no alkali)	0.3	
p-phenylene diamine hydrochloride (with alkali)	0.4	
Hydrochinon	1.0	Standard
p-phenyl glycin (glycin)	1.6	
Hydroxylamine	2.0	
Toluhydrochinon	2.2	
p-amidophenol (hydrochloride)	6.0	
Chlorhydrochinon (adurol)	7.0	
Dimethyl p-aminophenol sulphate	10.0	
Monomethyl p-aminophenol sulphate (metol)	20.0	
Diamidophenol (amidol)	30–40	

In general the higher the value of the reducing energy the higher is gamma infinity, but there are several exceptions which are not yet completely understood. Contrary to what might be expected, there appears to be no direct relation between the fogging power of a developer and its reducing energy or reduction potential.

General Reference Works

Eder—Ausführliches Handbuch Photographie, vol. IV, 1905.
Hübl—Entwicklung der Photographischen Bromsilbergelatineplatte, 1922.
Luther—Die chemischen Vorgänge in der Photographie, 1899.
Nietz—Theory of Development, 1922.
Reiss—Entwicklung der Photographischen Bromsilbergelatinetrockenplatte.
Seyewetz—Le Négatif en Photographie, 1922.

CHAPTER XII

ORGANIC DEVELOPING AGENTS

Developing Power.—The sensitive emulsion, as we have seen, consists of certain halide salts of silver in an extremely fine state of division held in a colloidal medium. We have already considered in the chapter on the latent image the various theories proposed to explain the nature of the change which occurs when the sensitive silver salts are exposed to light. While we do not know the composition of the latent image, we do know that there are certain chemical compounds which possess the property of reducing to metallic silver those grains of silver halide which have been affected by light. Such chemical substances are known as *developers* since they " develop," or render visible, the latent image formed by light. All developing agents are reducers, but not all reducers are capable of photographic development by any means. We are not yet in a position to say definitely what constitutes developing power; i.e. what must be the chemical composition of a substance in order that it may function as a developer. The general conclusions of Lumiere and Andresen bearing on this subject will be discussed later.

While in common speech a developer is taken to mean either the developing agent or the solution used for development, in this chapter we are concerned primarily with the developing agent and all reference to a developer applies to a particular agent such as metol, pyro, etc., and not to a developing solution as applied to the plate. This is always termed the *developing solution.*

Classification of Developing Agents.—A comparatively large number of substances possess the property of developing exposed silver halide but for various reasons only a few of these are of practical value. Eder[1] divides all possible developing substances into three classes:

1. Those which develop a definite part of the latent image before fog sets in. (Common developers.)

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[1] Ausführliches Handbuch der Photographie, p. 288 et seq.

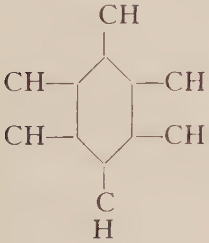
2. Those which develop energetically with a minimum of alkali but produce serious fog. (Powerful developers.)
3. Those which scarcely develop the latent image at all even with a maximum of alkali and yet develop fog vigorously.

A somewhat more comprehensive classification is adopted by Nietz.[2]

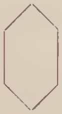
1. Developers having too low reducing energy to be useful practically, e.g. ferrous citrate.
2. Developers giving undesirable reaction products in developing, e.g. hydrazine.
3. Developers too powerful for ordinary use, e.g. triamidophenol.
4. Developers of practical utility, e.g. all ordinary developing agents, metol, pyro, paramidophenol, etc.

Only this last class will be discussed in the present chapter although references are made to several of the others in the bibliography at the close of the chapter.

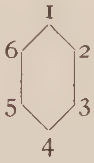
The Source of Organic Developing Agents.—Benzene, the source of the numerous aniline and phenol dyes, from which the organic developing agents are derived, was discovered by Faraday in 1825, but it was not until 1866 that its structural formula was determined by Kekulè. This consists of a hexagon with the carbon and hydrogen atoms linked together around the six points.



(1)



(2)



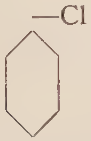
(3)

1. The structural formula of benzene after Kekulè.
2. Its abbreviated form generally referred to as the *benzene nucleus.*
3. The points of substitution.

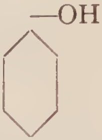
The atoms of hydrogen at any of the six points of substitution may be replaced by atoms of chlorine, hydroxyl, or amino groups, and, as a substance with entirely different properties is formed according to the

[2] *Theory of Development,* p. 14.

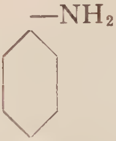
group substituted and the point at which substitution is made, it can be readily seen that a very large number of compounds become possible. By substituting chlorine, hydroxyl or amino groups in the first position we secure:



Chloro-benzene

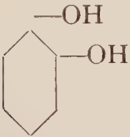


Hydroxy-benzene

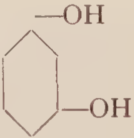


Amino-benzene
or Aniline

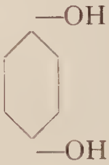
None of these compounds has any developing power. However, if we replace the two hydrogen atoms at positions 1 and 2, at 1 and 3, or at 1 and 4, we get three hydroxy-benzenes having the formula $C_6H_4(OH)_2$ and identical in composition but differing in constitution.



Ortho-
hydroxy-benzene
or Pyrocatechin



Meta-
hydroxy-benzene
or Resorcin



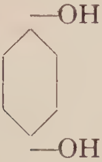
Para-
hydroxy-benzene
or Hydroquinone

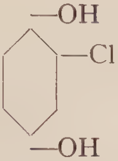
Substitution in the 1 and 2 positions is termed the *ortho* position, 1 and 3 the *meta* position, and 1 and 4 is termed the *para* position. Of the three compounds two are developers, *para*-hydroxybenzene being the agent known as hydroquinone while *ortho*-hydroxybenzene is known commercially as pyrocatechin. The third compound, *meta*-hydroxybenzene or resorcin, has little or no developing power.

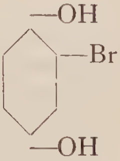
The developing properties of hydroquinone were discovered by Abney in 1880. As a developer, hydroquinone is rather slow and tends to strong contrast. It is very sensitive to low temperature and should not be used below 50° Fahr. (10° C.) Alone hydroquinone is employed chiefly for copies of black and white originals where a high degree of contrast is essential. A suitable formula will be found on page 287. For general work it is usually combined with metol.

Pyrocatechin is a more energetic developer than hydroquinone and less sensitive to low temperature. It is now little used.

By replacing the hydrogen atom in the second position of para-hydroxybenzene, or hydroquinone, with chlorine, Hauff produced *monochlor-hydroquinone* ($C_6H_3Cl(OH)_2$) which was introduced commercially as *Adurol.* Schering substituted bromine in the same way and obtained mono-*bromo*-hydroquinone ($C_6H_3Br(OH)_2$) which also was introduced as Adurol.

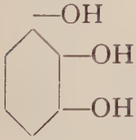

Hydroquinone

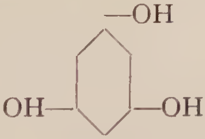

Adurol (Hauff)

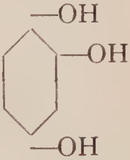

Adurol (Schering)

Adurol is a more energetic developer which works somewhat softer than hydroquinone, standing, in this respect midway between hydroquinone and the rapid soft-working developers such as metol and paraminophenol. It is not as sensitive to low temperature as hydroquinone and has a longer useful life. It is usually used in combination with metol.

Having dealt with the developing agents formed by substituting two hydroxyl groups in the benzene nucleus, let us see the effect of adding a third. There are three positions also which we can obtain by this treatment: that in which all three groups are close together, or adjacent; that in which two are contiguous, and the third separated by one position; and lastly that in which the groups are symmetrically placed.


Pyrogallol


Phloroglucinol

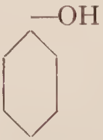

1, 2, 4 Trihydroxy benzene

These are known as adjacent, asymmetrical and symmetrical *tri*-hydroxybenzenes or as pyrogallol, oxyhydroquinone and phloroglucinol. Pyro is the only one of these substances used as a developer.

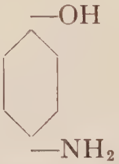
Pyro has been in use longer than any other organic developer and is still extensively used. Its character as a developer depends largely on the concentration at which it is employed; strong solutions develop rapidly with strong contrast while weaker solutions act more slowly and with less contrast. Solutions of pyro oxidize rapidly and in development the reduction of the pyrogallol on the silver image results in a super-imposed stain image which gives to the pyro-developed negative its characteristic brownish-black color. The intensity of the stain image can be controlled by the proportion of sodium sulphite used.

Precisely the same condition of affairs applies when the substitution is made with amino groups instead of hydroxyl groups. Thus we may have ortho, para, or meta aminophenols, or we may substitute instead two amino groups or one amino and one hydroxyl group thus producing a whole series of amino-hydroxybenzenes. Pursuing the same idea further we may replace one of the hydrogen atoms with a methyl group (CH_3).

For example if we introduce an amino group in place of a hydrogen atom in the fourth position in phenol we obtain para-amino-phenol which is well known as the base of such prepared developers as Rodinal, Azol, Activol, etc.



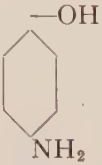
Phenol



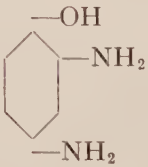
Paraminophenol (base)

Paraminophenol when used with the alkaline carbonates is a rapid, soft-working developer which readily produces detail but builds up density and contrast only with prolonged development. When made up in alkaline solution with the alkaline carbonates, the free base is liberated on standing and there is a gradual loss of developing power. Paraminophenol is more generally employed in the form represented by the so-called " Rodinals " which will be noticed later.

The introduction of a second amino group produces di-amino-phenol or the familiar amidol.



Paraminophenol



Diaminophenol or Amidol

Amidol differs from all the developers already mentioned in that it can develop without an alkali and may be used in an acid solution. It is a very rapid developer; the image appears quickly, but density and contrast are added only on prolonged development. Stock solutions of amidol loose their developing power in from one to two days without the visible discoloration which accompanies the oxidation of other developing agents. Amidol is used principally for the development of prints. As it develops fog when used in alkaline solution, care should be taken that the sodium sulphite employed does not have an alkaline reaction. This may be corrected by the addition of sodium bisulphite.

Stock solutions of amidol which will keep for several days may be prepared by the use of neutralized sulphite prepared as follows:

Sodium sulphite (dry)	2 oz.	91.2 gm.
Potassium metabisulphite	½ oz.	22.8 gm.
Water to make	20 oz.	1000 cc.

Boiling for several minutes improves the keeping quality of this solution.

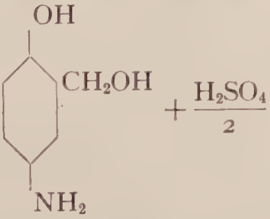
The developer is prepared as follows:

Amidol	40 gr.	4.2 gm.
Stock solution	4 oz.	200 cc.
Water to	20 oz.	1000 cc.

A number of other methods of preserving solutions of amidol have been suggested. Namias advised the use of boric acid in the proportion of 25 grains to the ounce of solution; Crowther,[3] the use of glycollic acid in proportion to 1/10 the quantity of sodium sulphite; Bunel,[4] the addition of lactic acid one part to fifty of the solution; and Desalme,[5] the use of tin chloride 1:25.

There are four more developers which may be regarded as being derived from paraminophenol, namely, Edinol, Metol, Glycin and Ortol.

Edinol is the sulphate of oxymethyl-paraminophenol; the relationship to paraminophenol being clear from the structural formula:



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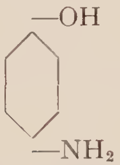
[3] *Brit. J. Phot.*, 1920, **67**, 642.

[4] *Bull. Soc. Franc. Phot.*, 1921, , 290.

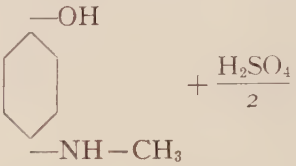
[5] *Brit. J. Phot.*, 1921, **68**, 359.

As a developer Edinol is fairly energetic and is free from any tendency to stain or cause fog. It may be used alone but is more generally employed in combination with adurol or hydrochinon.

If paraminophenol be taken, and one hydrogen atom of the amino group be replaced by a methyl group we secure mono-methyl-paraminophenol. The sulphate of this is sold commercially as metol.



Paraminophenol

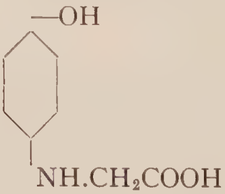


Metol

Metol was introduced commercially by Hauff in 1891, the metol issued at that time being dimethylparamino-meta-cresol, the cresol base being abandoned later in favor of phenol.[6]

Metol is one of the most conspicuous members of the class of soft-working developers which include also paraminophenol and diaminophenol, or amidol. Metol is seldom used alone but generally with hydroquinone or adurol; the rapid soft-working character of metol being supplemented by the greater density-giving powers of hydroquinone or adurol. Although metol is much more energetic than hydroquinone, a combination of the two is more rapid than either alone, due to the fact that metol brings out the detail of the image very quickly while hydroquinone adds the density and contrast necessary for good printing quality. The combined metol-hydroquinone developer is one of the most popular in existence.

Glycine is produced by inserting the carboxyl group in place of a hydrogen atom in the methyl group of metol, being para-oxyphenyl-glycine.



Glycine

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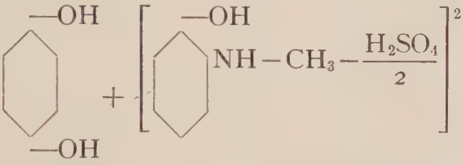
[6] The patents taken out for metol covered only its use as a developer and did not disclose either its composition or preparation. Methods of preparing mono-methyl-paraminophenol, or "metol," however, were discovered in several quarters during the World War. See Ermen, *Phot. J.*, 1923, **63**, 223.

As a developer glycine is slow but powerful, and is especially notable for the fine-grain of the reduced silver and the freedom from veil even in the absence of a soluble bromide. It keeps well in solution and is especially adapted to continuous use in tanks.[7]

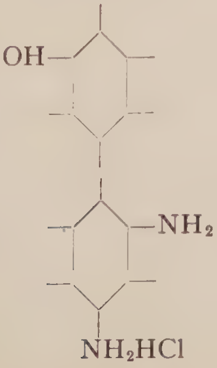
Ortol is a mixture of hydroquinone and the sulphate of methylorthoaminolphenol. The probable formula is



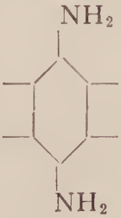
Ortol

Used alone, Ortol bears a close resemblance to pyro, not only as respects the color of the image, which is brownish-black, but in the progressive appearance of the image. As with pyro, the highlights appear first, followed by the half-tones and lastly the shadows; this gradual building up of the image is quite different from the action of metol and other rapid developers in which the highlights, half-tones, and shadows appear at very nearly the same time and density is built up later. Ortol, unlike pyro, however, does not stain and in solution keeps much better.

There are two other developers derived from benzene, diphenal and paraphenylene diamine; these, however, are not very important. The last is occasionally used for lantern slides and transparencies on account of the very fine-grained images which is produced and would be useful for line work were its contrast-giving properties greater.



Diphenal



Paraphenylene diamine

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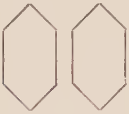
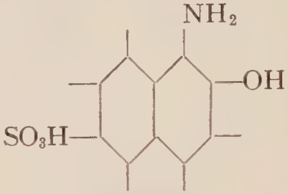
[7] See, *Brit. J. Phot.*, 1928, **75**, 514.

If two benzene nuclei are joined together, as shown below, we obtain a body called naphthalene. If we introduce into this hydroxyl, amino and sulphonic acid groups we obtain a substance which may be termed β amino, β_1 naphthol, β_3 sulphonic acid, known to photographers as Eikonogen.



Naphthalene



Eikonogen

As a developer Eikonogen is rapid, though not so energetic as metol, and tends to give very soft images. It is generally used with hydroquinone in order to secure greater density. Solutions of Eikonogen do not keep as well as those of metol and the combination of metol and hydroquinone has almost completely replaced Eikonogen.

A chemical compound of metol and hydroquinone was introduced by Lumière in 1903 as metoquinone. Chloranol, another developer introduced by Lumière, is a compound of hydroquinone and methylparaminophenol. Hydramine, a chemical combination of hydroquinone and paraphenylenediamine was also introduced by Lumière. All of these combinations are of minor importance.

The relationship of the various developing agents and some of the methods of derivation are shown in the following family tree of the coal-tar developers as compiled by Dwight R. Furness.[8] All of the methods are not shown, only those of importance are dealt with for the sake of simplicity.

The Significance of Group Relations.—Most of our knowledge of the structure of developing agents and the relation of the structure to developing properties is due to A. and L. Lumière and to Andresen. The papers of these investigators have established some general rules for the structure of compounds which possess developing power. It is now generally accepted that the presence of hydroxyl or amino groups, either alone or in combination, is necessary in order that a substance may function as a developer.

With substances which contain in one benzene nucleus at least two hydroxyl groups, two amino groups, or one hydroxyl and one amino group:

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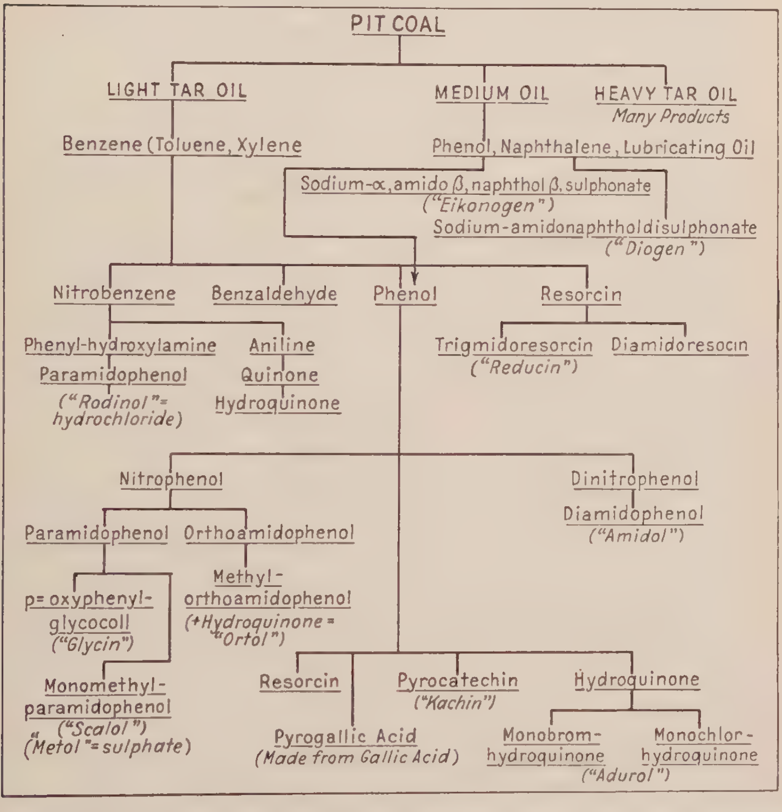
[8] *Phot. J. of Amer.*, 1918, p. 337.

1. The substance is a developer only when the groups are in the *ortho* or *para* position. *Meta* compounds, so far as known, have no developing power.
2. In general *para* compounds possess greater energy than do *ortho* compounds.


PIT COAL
LIGHT TAR OIL
MEDIUM OIL
HEAVY TAR OIL
Many Products
Benzene (Toluene, Xylene
Phenol, Naphthalene, Lubricating Oil
Sodium-α, amido β, naphthol β, sulphonate
("Eikonogen")
Sodium-amidonaphtholdisulphonate
("Diogen")
Nitrobenzene
Benzaldehyde
Phenol
Resorcin
Phenyl-hydroxylamine
Aniline
Trigmidoresorcin
("Reducin")
Diamidoresocin
Paramidophenol
Quinone
("Rodinol"= hydrochloride)
Hydroquinone
Nitrophenol
Dinitrophenol
Diamidophenol
("Amidol")
Paramidophenol
Orthoamidophenol
p= oxyphenyl-glycocoll
("Glycin")
Methyl-orthoamidophenol
(+Hydroquinone = "Ortol")
Monomethyl-paramidophenol
" ("Scalol")
(Metol"= sulphate)
Resorcin
Pyrocatechin
("Kachin")
Hydroquinone
Pyrogallic Acid
(Made from Gallic Acid)
Monobrom-hydroquinone
Monochlor-hydroquinone
("Adurol")

3. The di-oxy-benzenes are more powerful than the amidophenols which are in turn more powerful than the diamido benzenes.
4. The developing power is not destroyed by additional hydroxyl or amido groups.
5. In the naphthalene series it is not necessary that both groups be joined to the same benzene nucleus. The general rules regarding developing function do not apply to this group.

CHARACTERISTICS OF PHOTOGRAPHIC DEVELOPING AGENTS

Agent	Solubility		Keeping Properties of Solutions		Watkins Factor[12]	T. C.	Effect of Dilution Hübl[13]	Exhaustion Strauss[14]
	in gms. per liter H_2O	in gms. liter 5 per cent Na_2SO_3	Hübl[10]	Milbauer[11]				
Adurol	13.0	19.8	0.6	6.0	5	—	2	6
Amidol	15.9	9.7	—	0.16	18^x	—	1.1	—
Eikonogen	7.6	8.2	0.6	1.2	9	—	2.6	2
Glycine	0.023	12.8	1.0	9.0	$8–12^x$	—	2.5	5
Hydroquinone	5.7	7.4	0.4	4.0	5^x	2.4	3.8	3
Metol	4.8	4.5	0.5	7.0	30	1.9	—	10
Paraminophenol	33.0	3.2	0.5	—	16	1.9	1.75	9
Pyrocatechin	33.0	35.7	0.6	8.0	10	—	2.16	4
Pyro	52.4	41.8	—	1.0	$8–18^x$	1.9	2.0	1
Edinol	15.9	9.7	—	5.0	20	—	—	8
Ortol	—	—	—	5.0	10	2.06	—	7
Rodinal	—	—	0.9	2.5	—	—	1.75	—

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[9] Table of Solubilities from Kail, *Phot. Ind.*, 1921, p. 168.

[10] Hübl, *Die Entwicklung.* These figures represent the difference in time of development of fresh solutions and those left standing in an open tray for several hours. Thus 0.5 indicates that the rapidity of the oxidized bath is only half that of the fresh solution.

[11] Milbauer, *Phot. Korr.*, 1917, **54**, 232. Milbauer's figures refer more particularly to the keeping properties of the stock solutions.

[12] The Watkins factor for amidol, glycine, and pyro vary with the concentration, amount of soluble bromide employed, and the alkali used.

[13] Hübl, *Die Entwicklung.* The figures refer to the difference in time of development when the developing solution is diluted with an equal amount of water.

[14] Strauss, *Phot. Ind.*, 1925, p. 309. These figures express simply the order in which the different agents are exhausted with continuous use; thus pyro developers are exhausted more quickly than ortol or glycine, and metol and paraminophenol less quickly than adurol or edinol.

FORMULÆ FOR THE PRINCIPAL DEVELOPING AGENTS

(In parts to 1000 solution)

Solution No. I	Adurol (1)	Glycine	Hydroquinone	Hydroquinone (contrast)	Metol	Ortol	Paraminophenol	Pyro (2)	Pyrocatechin (3)
Developing agent	20	20	20	25	15	15	25	33	20
Sodium bisulphite	—	—	—	25	—	7.5	12	16	—
Sodium sulphite (anhydrous)	100	50	100	—	75	—	—	200	37.5
Potassium bromide	—	—	—	25	—	—	—	—	—
Potassium carbonate	—	10	—	—	—	—	—	—	—
Water to	1000	1000	1000	1000	1000	1000	1000	1000	1000
Solution No. II									
Sodium carbonate (anhydrous)	—	—	—	—	60	60	60	185	—
Potassium carbonate	120	100	120	—	—	—	—	—	125
Sodium hydroxide	—	—	—	45	—	—	—	—	—
Potassium bromide	—	—	—	—	—	1	—	8.5	—
Sodium sulphite (anhydrous)	—	—	—	—	—	90	30	—	—
Water to	1000	1000	1000	1000	1000	1000	1000	1000	1000

FOR USE: Take equal parts of Solution I and Solution II, except

(1) dilute with equal part of water;

(2) dilute with seven parts of water;

(3) for use take one part of Solution I to two parts of Solution II.

Sodium carbonate may be substituted for the potassium salt on a basis of 23 parts of the former for 30 parts of the latter. With glycine and hydroquinone, however, the potassium salt is to be preferred.

COMBINED DEVELOPERS

Solution No. I	Metol glycine	Metol hydroquinone	Metol adurol	Pyro glycine	Pyro metol
Water to	1000 parts	1000 parts	1000 parts	1000 parts	1000 parts
Metol	200 "	5 "	5 "	—	8 "
Hydroquinone	—	8 "	—	—	—
Adurol	—	—	10 "	—	—
Pyro	—	—	—	5 "	9.2 "
Glycine	100 "	—	—	10 "	—
Sodium sulphite (anhydrous)	375 "	60 "	50 "	25 "	—
Potassium metabisulphite	—	—	—	—	20 "
Potassium bromide	—	—	—	—	3.5 "
Solution No. II					
Water to	1000 parts	1000 parts	1000 parts	1000 parts	1000 parts
Potassium carbonate	1500 "	75 "	100 "	40 "	—
Sodium carbonate (anhydrous)	—	—	—	—	75 "

FOR USE: Take equal parts of Solution I and Solution II, except

(1) dilute with equal part of water;

(2) dilute with seven parts of water;

(3) for use take one part of Solution I to two parts of Solution II.

Sodium carbonate may be substituted for the potassium salt on a basis of 23 parts of the former for 30 parts of the latter. With glycine and hydroquinone, however, the potassium salt is to be preferred.

In each case take equal parts I and II.

6. The substitution of chlorine or bromine for hydrogen increases the developing energy.
7. A substance containing two hydroxyl groups requires an alkali, while substances containing two amino groups or one hydroxyl and one amido group do *not* require an alkali.

In substances containing three hydroxyl or amino groups either alone or in combination:

1. Symmetrical arrangements, as 1, 3, 5, have no developing power. Other arrangements differ in developing energy but no definite rule has been found to apply.
2. Hydroxyl-phenols, containing three hydroxyl groups, can develop without alkali but are not practical when so used.
3. Increasing the number of amino groups increases the energy of the developing agent.

Phenolate Compounds.—Towards strong alkalis paraminophenol acts as an acid, therefore if the hydrogen atom of the hydroxyl group is replaced by an alkali metal such as sodium, a *phenolate* compound results having in this case the formula $C_6H_4ONaNH_2$ or sodium paraminophenolate. This is actually the substance formed when a solution of caustic soda is added to a paraminophenol developer in order to redissolve the precipitated free base. Advantage is taken of this fact to prepare highly concentrated solutions of paraminophenol which simply require dilution with water in order to be ready for immediate use. It is in such form that paraminophenol has achieved its greatest popularity under the names of Rodinal, Citol, Azol, Activol, Certinal, Paranol and Kalogen. These are all patented substances, but a developer of similar composition can be prepared by the formula to follow:

Bring to a boil 250 cc. of pure water and, when just before the boiling point, add a few crystals of potassium metabisulphite; when these are dissolved add 20 grams of paraminophenol hydrochloride and finally 60 grams of potassium metabisulphite. The mixture is stirred until all of the metabisulphite has dissolved, and there is then added, with constant stirring, liquid commercial caustic soda sufficient to redissolve the aminophenol base. The mixture becomes thick at first owing to the precipitation of the aminophenol base and as the caustic soda is added gradually clears up owing to the precipitated base going into solution. The addition of caustic soda should be stopped just *before* all of the paraminophenol base is dissolved and the solution made up to 400 cc., placed in a rubber-stoppered bottle and allowed to cool. *It is very important that a small quantity of paraminophenol base be left undissolved as the least excess of caustic soda causes the solution to be unstable, rapidly turning brown and losing developing power.* This is the only trick in the operation and must be carefully observed. A solution properly prepared will keep almost indefinitely. Should an excess of caustic soda be added by mistake, the matter may be remedied by the addition immediately of a solution of sodium bisulphite until a slight precipitate of paraminophenol is formed.[15]

Fine-Grain Developers.—The degree of inhomogeneity, or as commonly termed, the graininess of the developed image assumes considerable importance when the negative is to be subsequently enlarged. It is necessary at this point to draw a distinction between the grain of the individual silver grain and the graininess which results from the aggregation or clumping of these. It is the latter which is the cause of the graininess observed in ordinary enlargements; the effect of the individual grains is evident only upon much higher magnification.

Absolute graininess varies with different emulsions, being, in general, greater with rapid than with slow materials, and increases with the contrast, or γ, of the negative.

Physical development results in an image of finer grain and the use of paraphenylene was recommended for this purpose by A. and L. Lumière and A. Seyewetz[16] in 1904. Development with paraphenylene, however, is a very exacting process and the contrast of the image is too low for ordinary requirements. Furthermore, a considerable increase in exposure is required. Later they recommended the use of paraphenylene diamine with a weak alkali, such as borax, which results in more rapid development and higher contrast, with but little increase in the size of grain.[17]

At the present time, however, the most practical developer for securing fine grain for subsequent enlargement seems to be the special metol-hydroquinone-borax formula developed by the Kodak Research Laboratories. This is as follows:

[15] Metol and Monomet may also be used to prepare developers of this character. For full directions see Ermen, *Brit. J. Phot.*, 1920, **67**, 611; see also pp. 610–611.

[16] *Bull. Soc. Franc. Phot.*, 1904, **20**, 422.

[17] *S. I. P.*, 1927, **7**, 107.

Metol	15 gr.	2 gm.
Sodium sulphite (anhydrous)	768 gr.	100 gm.
Hydroquinone	38 gr.	5 gm.
Borax	15 gr.	2 gm.
Water	16 oz.	1000 cc.

The metol is dissolved first in a small quantity of water; a quarter of the sulphite next in hot water, the hydroquinone added, and this solution is then added to the solution of metol. The remaining sulphite is now dissolved in additional water, the borax added and this solution added to the other, water being added to bring the total bulk to 16 ounces or 1000 cc.[18]

The finer grain is due apparently to the high sulphite content as well as to the low alkalinity.[19] On this last account, development is comparatively slow, requiring 15–25 minutes at 65° Fahr.

Developers for Continuous Use.—It is the general practice in the larger commercial establishments and in motion picture processing laboratories to develop in large tanks holding several gallons of developer until the solution ceases to function properly. While from a theoretical standpoint, it is far better, particularly with highly sensitive panchromatic materials, to use a fresh solution for each batch of plates or film, in practice, satisfactory negative quality is secured by continuous use of the developer provided the solution is discarded when it has reached its effective limit.

In the choice of the developing agent for continuous use in tanks, both the keeping qualities of the solution and the rate of exhaustion are of importance. As regards keeping qualities, an exact comparison between the figures obtained by Hübl and Milbauer (table on page 286) is difficult owing to experimental differences; both agree, however, in assigning superior keeping qualities to glycin, followed by pyrocatechin and adurol. The studies of Strauss[20] on the effect of repeated use of developers shows that metol has the longest useful life followed by paraminophenol, edinol, ortol, adurol, glycin, pyrocatechin, hydroquinone, and, much worse than the others eikonogen and pyro. Metol-hydroquinone, or preferably metol-adurol, metol-glycin, and glycin, therefore, appear on theoretical considerations, to be the most suitable for continuous use in tanks. The widespread use of metol-

[18] *Brit. J. Phot.*, 1928, **75**, 74.

[19] Cf. Veldmann, *Das Atelier*, 1928, **35**, 30.

[20] *Phot. Ind.*, 1925, p. 309.

hydroquinone and glycin in the processing of motion picture film by automatic machinery indicates that in practice these developers have been found best adapted to continuous use.

GENERAL REFERENCE WORKS

EDER—Ausführliches Handbuch der Photographie.
SEYEWETZ—Le Negatif en Photographie.
VALENTA—Photographische Chemie und Chemikalienkunde.

CHAPTER XIII

THE TECHNIQUE OF DEVELOPMENT

Introduction.—The chemical and physico-chemical basis of the process of development and the chemical and photographic properties of the organic compounds used for development have formed the subject of the two preceding chapters. In this, the last chapter on the subject, we will be concerned for the most part with the more practical aspects of the matter—the technique of development.

The developing solution as applied to the plate consists of four ingredients: the developing agent itself; the preservative, generally sodium sulphite; the alkali, one of the alkaline carbonates usually; and the restrainer, potassium bromide. Amidol is an apparent exception to this as no alkali is added, but it is probable that the hydrolysis of the sulphite which is always used furnishes the sodium to form a phenolate which is the actual developing agent. Then again the restrainer is quite often omitted, particularly in negative developing solutions, but generally we may say that the developing solution consists of the developing agent, the preservative, the alkali, and the restrainer. The part played by each of these in the process of development has already been considered; there remain, however, a few matters of practical importance regarding the use of the sulphites and alkalis in development. These matters it is proposed to take up in the present chapter, together with desensitizing as applied to photographic development, and finally the three principal methods of development: inspection, factorial and thermo.

The Sulphites in Development.—The use of sodium sulphite as a preservative in solutions of the organic developing agents appears to have been first suggested by Berkeley in 1882.[1] The theory of its action has already been discussed (page 257).

There are two forms of sodium sulphite in general use, the anhydrous and the crystalline, the latter containing seven molecules of water of crystallization having the formula $Na_2SO_3 \cdot 7H_2O$. Calculating the molecular weights of the two forms we have

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[1] *Phot. J.*, 1882, **22**; *Brit. J. Phot.*, 1882, **29**, 47; *Phot. News*, 1882, **26**, 41.

$$Na_2SO_3 = 126$$
$$Na_2SO_3 \cdot 7H_2O = 252.$$

Thus 126 parts of the anhydrous are equivalent to 252 of the crystalline salt, or, in other words, the anhydrous form is just exactly twice as strong as the crystal. Hence when using anhydrous sulphite in a solution calling for crystals only one half of the amount called for by the formula should be used. As the crystal form is in almost universal use in England whereas the anhydrous is in general use in this country, this fact should be borne in mind when making use of formulas from an English source.

No matter which salt is used it is rare to find it pure, and commercial varieties are likely to contain from 2 to as much as 10 per cent of impurities principally as sulphates or as carbonates. While theoretically one ought to test each batch, this is unnecessary since an excess is always used. Of the two forms the anhydrous keeps better in the dry state and for this reason is to be preferred over the crystalline form.

Stock solutions of sulphite do not keep well and it is advisable to prepare at one time no more than it is expected to use within a week to ten days. Specially prepared solutions of sulphite containing alcohol or potassium metabisulphite, however, may be kept much longer. The addition of 10 per cent of alcohol has a beneficial effect on the keeping properties while the so-called "neutral sulphite" is even more effective. Most commercial sulphite is slightly alkaline and this affects the keeping properties, hence the addition of just sufficient acid to neutralize the sulphite is often advised. Sulphuric is the best of the strong acids for this purpose although oxalic and citric acid are often used. Perhaps the most effective means of preserving sodium sulphite solutions is by the use of potassium metabisulphite as follows:

Sodium sulphite (dry)	2 oz.	100 gm.
Potassium metabisulphite	½ oz.	25 gm.
Water to make	20 oz.	1000 cc.

Dissolve at ordinary temperature, then raise to the boiling point and finally allow to cool.[2]

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[2] The addition of small quantities of hydrochinon as a preservative of stock solutions of sulphite has recently been suggested. See *Journ. Camera Club of London*, 1923, I, 3.

In place of sodium sulphite the corresponding potassium and ammonium sulphites have been recommended, as have also potassium metabisulphite and sodium bisulphite lye, but owing to the cheapness and efficiency of sodium sulphite none of these compounds have ever been widely adopted.[3]

In the case of a developing agent producing a stain image, the proportion of sulphite controls the intensity of the stain. Thus in the case of pyro, increasing the amount of sulphite will decrease the amount of stain to a point where the image is almost pure black, while if the sulphite is decreased the intensity of the stain will gradually increase, passing from black to warm-black, and finally to yellowish-brown. With non-staining developers the proportion of sulphite does not have any decided influence on the color of the deposit, acting principally as a preservative of the developing solution.

The Alkalis in Development.—When alkaline development was first introduced by Russel in 1862 the alkali in common use was ammonia and pyro-ammonia continued to be the favorite developer for many years. Even as late as 1900 pyro-ammonia was still considerably used for negative work. Owing, however, to its volatile nature its action is erratic and uncertain and at present ammonia has been completely replaced in all but a few instances by the fixed alkalis such as the alkaline carbonates and hydroxides.

Of these the carbonates are the most widely used, particularly sodium carbonate. Potassium carbonate is used in some special cases, while the hydroxides are occasionally used with hydrochinon and glycin, or for the production of phenolate compounds from paramidophenol.

There are three carbonates of sodium, the bicarbonate or acid carbonate, the sesqui-carbonate and the normal carbonate. Only the latter is suitable for development. The normal carbonate exists in three forms, the anhydrous Na_2CO_3, the monohydrate containing one molecule of water and having the formula $Na_2CO_3 \cdot H_2O$ and the crystalline having ten molecules of water of crystallization and consequently being $Na_2CO_3 \cdot 10H_2O$. Calculating the molecular weights of the three forms:

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[3] Ammonium sulphite, Eder, *Phot. Korr.*, 1885, **22**, 111. Potassium metabisulphite, Mawson and Swan, *Brit. J. Almanac*, 1887, p. 139; 1888, pp. 316 and 346. Sodium bisulphite lye, Gilder, *B. J. Almanac*, 1891, p. 718.

Crystalline	$Na_2CO_3 \cdot 10H_2O$
	$46 + 60 + 180 = 286$,
Monohydrate	$Na_2CO_3 \cdot H_2O$
	$46 + 60 + 18 = 124$,
Anhydrous	Na_2CO_3
	$46 + 60 = 106$.

Consequently we see that 106 parts of anhydrous sodium carbonate are equal to 124 of the monohydrate and 286 of the crystalline form. The anhydrous carbonate is therefore approximately 2.8 times as efficient as the crystalline. As a matter of fact, however, the pure anhydrous carbonate is not often met with, the usual dry or so-called "anhydrous carbonate" being in reality the monohydrate, $Na_2CO_3 \cdot H_2O$. This is slightly stronger by twice than the crystalline salt as 286 : 124 :: 100 : 43.4. It is quite accurate enough, however, for all practical purposes to take the efficiency of the ordinary dry sodium carbonate as being twice that of the crystalline form. The monohydrate is generally used in this country, the crystalline form, however, is still used in England—a fact which must be borne in mind when using formulas from that country, as, unless specified as dry, the quantities always represent crystal carbonate.

The monohydrate is to be preferred to the crystalline salt owing to the fact that it is more stable, as it does not effloresce or lose its water of crystallization. The crystal carbonate owing to its larger water content is also more apt to absorb carbon dioxide from the air. This unites with the carbonate to form bicarbonate, a substance of no practical value in development.

There is no settled proportion of alkali which should be used with any given plate or developing agent. Variations within reason have no other practical effect than increasing or decreasing the velocity of development. The existence of an optimum concentration of alkali beyond which no further increase in velocity occurs when the alkali is increased has been shown by Ermen.[4] Except in the case of hydrochinon, this optimum concentration equals about 1 per cent of the anhydrous salt. Increasing the carbonate above this point does not increase either the velocity of the developer, nor the density, but probably does increase the amount of fog and for this reason should be avoided.

Not much use is made of the caustic alkalis, such as the sodium and potassium hydroxides, except for the preparation of paramidophenol developers and with such slow acting agents as hydrochinon and glycin. When used with hydrochinon, the caustic alkalis form a more active developer, which works more rapidly and softer than that produced by the use of the alkaline carbonates and one which is less affected by temperature. Owing to their supposed tendency to fog and to their action on gelatine there exists a certain prejudice in the minds of many photographers against the use of the caustic alkalis. While with the more energetic developing agents no real advantage attends the use of the same over the alkaline carbonates, the caustic alkalis may be used with complete success if care be taken to use the proper amount The following table shows the developing equivalence of the alkalis and in what proportion one should be substituted for another.

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[4] *Phot. J.*, 1922, **62**, 123.

Sodium hydroxide	Potassium hydroxide	Sodium carbonate Na_2CO_3	Sodium carbonate $Na_2CO_3 \cdot H_2O$	Sodium carbonate $Na_2CO_3 \cdot 10H_2O$	Potassium carbonate K_2CO_3
80	112	106	124	286	138
1.	1.40	1.325	1.550	3.575	1.725
0.714	1.	0.946	1.106	2.553	1.232
0.755	1.057	1.	1.170	2.699	1.302
0.323	0.452	0.428	1.	1.155	.557
0.280	0.392	0.371	0.434	1.	0.483
0.580	0.812	0.768	0.899	2.072	1.

A number of other substances have been suggested for use in place of the alkaline carbonates and hydroxides but few have come to be used extensively. Sodium tribasic phosphate was suggested by Lumière in 1906 but has never been widely used. Acetone $CH_3 CO \cdot CH_3$ was also recommended by Lumière and has found some favor, particularly in conjunction with pyro. Its action is to combine with the sulphite to form acetone sulphite, the sodium set free combining with the developing agent to produce the phenolate which is the actual reducing agent. Its principal advantages are its freedom from fog, somewhat less stain than when the alkaline carbonates are used and no softening action on the gelatine film. Pyro-acetone for the latter reason makes a very efficient hot-weather developer. Formaldehyde was introduced by Lumière in 1898 but has not proved to be very efficient with any agent except hydrochinon in conjunction with which it produces a contrast working developer especially suitable for line copies and similar work in black and white.[5]

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[5] Sodium tribasic phosphate, *Eder's Jahrb.*, 1896, **10**, 190. Acetone, *Bull. Soc. franc. Phot.*, 1896, p. 558; 1897, p. 550. Formaldehyde, *Eder's Jahrb.*, 1898, **12**, 419.

The Value of Desensitizers.—One of the most noteworthy additions to photographic technique during the last few years has been the introduction of efficient desensitizing agents which by reducing the sensitiveness of the plate enable development to be conducted in a much brighter light than that which may be used otherwise. The great sensitiveness of the modern dry plate has made their development a matter of real difficulty for no light which is sufficiently bright to be of much value in practice may be used without danger of fog. Particularly is this true for plates which are extremely sensitive to color, such as the modern panchromatic for which no light is really safe and time and temperature methods are the only satisfactory manner of development. The use of a desensitizing agent, however, enables plates of the very highest sensitiveness to be developed with comparative safety in a bright yellow or orange light, thus considerably facilitating development by either the inspection or factorial methods.

Desensitizing Agents.—Although there are some scattered references in photographic literature prior to 1920 on the subject of desensitizing agents (see Wall, *Amer. Phot.*, 1921, **15**, 651, Dec.) phenosafranine, introduced as a result of the investigations of Dr. Luppo-Cramer, was the first really practical desensitizing agent. Phenosafranine used at a concentration of 1 : 2000 reduced the sensitiveness of an extra rapid plate to 1/750 of its original sensitiveness without any effect whatever on the latent image so that no increase in exposure is required. A. and L. Lumière and A. Seyewetz found that toluylene red 1 : 1000, aurantia 1 : 1000, picric acid 1 : 100 are all desensitizers but not so efficient as phenosafranine.[6]

Pinakryptol, pinakryptol green and pinakryptol yellow are three desensitizers of unknown constitution introduced by the Farbewerke vorm, Meister, Lucius and Brüning as the result of the investigations of Dr. E. König, B. Homolka and Robert Schuloff. Both pinakryptol and pinakryptol green are colored substances and form highly colored solutions but neither has any staining action on gelatine and are consequently superior in this respect to phenosafranine which stains strongly. The desensitizing effect of both is as high, if not higher, than that of phenosafranine. Pinakryptol slows development, but with pinakryptol green the rate of development is unaffected.

With both the reduction in sensitiveness is much greater for the blue rays than for the red so that with red-sensitive, panchromatic plates there is danger of fog. This difficulty has been overcome by the introduction of pinakryptol yellow which is a more effective desensitizer for the rays of longer wave-length. Its desensitizing power, however, is destroyed by sodium sulphite so that it cannot be added to the developing solution as can pinakryptol and pinakryptol green but must be used as a separate bath and followed either by a bath of pinakryptol green or a developing solution containing .005 per cent pinakryptol green.

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[6] *Brit. J. Phot.*, 1921, **68**, 351, 370.

Basic Scarlet N, a red dye made by the Compagnie des Matierès Colorantes of France was found to be an active sensitizer by the Research Laboratory of Pathé Cinéma. According to Moreau it consists of a mixture of chrysoidin and phenosafranine. As compared with pinakryptol green, it is stated to be more effective in preventing fog.

Mercury cyanide, the use of which as a desensitizer has been patented by the I. G. Farbenindustrie,[7] is the only desensitizing substance of practical utility yet found among inorganic substances. According to Mayer and Walter,[8] the actual desensitizer is the complex $K_2Hg(CN)_4$. As a desensitizer, mercury cyanide is as powerful as any of the organic substances known and is less prone to produce fog. It cannot be used as a preliminary bath, however, and is slowly precipitated in developers. It cannot be used with pyro. In use, 0.3 gram mercury cyanide is added to each liter of developer (4.6 gr. to 35 oz.).

Desensitizing in Practice.—Either phenosafranine, pinakryptol, pinakryptol green or basic scarlet N may be used as a preliminary bath, or as an addition to the developing solution. When used as a preliminary bath, phenosafranine is used at a dilution of 1 : 2000, pinakryptol, pinakryptol green and Basic Scarlet N at 1 : 5000. An immersion of two minutes is sufficient, although longer immersion is not objectionable in the least. After this the plate may be removed and development conducted in a bright yellow or orange light.

If the desensitizer is added to the developing solution, from two to three minutes should be allowed to elapse before turning on the brighter light. According to Dr. Luppo-Cramer, the action of phenosafranine is complete within one minute and pinakryptol green within practically the same time. Pinakryptol, however, is slower in action and requires about two minutes and in practice it may be well to increase these times slightly in order to be sure that the action is completed.

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[7] B. P. 280,525 of 1926; *Brit. J. Phot.*, 1928, 75, 233

[8] *Brit. J. Phot.*, 1928, 75, 692.

If the desensitized plate or film is exposed to bright orange or red light before it is placed in the developer or before the image has appeared the latent image will be bleached. Keep the plate covered the first few minutes of development.

Used as a preliminary bath, pinakryptol green increases fog with nearly all developers but particularly so with pyro. With glycin, elon (not metol-hydroquinone) and rodinal, however, there is little increase of fog.[9] Pinakryptol green is more effective when added to the developer than when used as a preliminary bath; a concentration of 1/25,000 in the developer being equal in desensitizing power to 1/5,000 used in a preliminary bath. There is also less tendency to produce fog when the desensitizer is added to the developing solution.[10] On the other hand, most developers tend to precipitate upon the addition of pinakryptol green. This is especially true of hydroquinone, less so with adurol, and pyro, while glycin, rodinal, paraminophenol and metol are not precipitated. With metol-hydroquinone, and probably with other developers, the desensitizing action exists at least as long as the activity of the developing solution.

Desensitizing affects the Watkins factor, reducing it in the case of pyro and amidol and increasing it in the case of hydroquinone, which it raises from a low-factor, slow-working agent to a high-factor, soft-working developer. Phenosafranine has, in fact, been advised by Lüppo-Cramer as a cheap substitute for metol with a hydroquinone developer.[11]

According to Hübl,[12] with hydroquinone the factor varies from 5.3 with phenosafranine, to 4.6 with pinakryptol yellow and 2.6 with pinakryptol. With a metol hydroquinone developer containing 3 parts metol to one of hydroquinone, the change in the factor is insignificant. With pyro and amidol the factor must be reduced one third.

Development by Inspection.—The first and perhaps the still most widely used method of development, certainly by the older workers, consists in visual examination of the plate from time to time. Determination of the time of development by inspection is largely a matter of experience. It is not a method which is founded upon any definite scientific basis, nor one which can be expressed in terms which convey any exact information to another worker. Continuous experience under standardized conditions, and this only, will enable one to achieve success in developing by inspection. It is true that there are a large number of tips or dodges which are used by the experienced worker as a guide, and which are often recommended to the beginner when in search of assistance, but these in the absence of similar experience convey no exact meaning and are applicable only to those conditions under which they originated. Under other circumstances and in other hands such indications may be wide of the mark and positively misleading.

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[9] Dundon and Crabtree, *Brit. J. Phot.*, 1926, **73**, 404.

[10] *Ibid.*

[11] *S. I. P.*, 1921, **1**, 69; *Phot. Ind.*, 1921, p. 534.

[12] *Amer. Phot.*, 1925, **19**, 642.

Actual photometric measurement of several sensitometric strips is sufficient to show how unreliable any attempt to estimate contrast by the eye is likely to be and when it is remembered that in development such estimation is made still more difficult by the presence of an opalescent film of silver halide which increases the apparent opacities, but decreases the ratio of the opacities, or the contrast, it is at once evident that development by inspection is subject to exceedingly large errors and that it is a method which can be practiced successfully only after considerable experience with a given plate and other standardized conditions.

With incorrect exposure the matter becomes still more complicated. The delayed appearance of the image and the slow increase in density and shadow detail in the case of under exposure leads to over development in the hope of securing greater density and more shadow detail. As a result the contrasts, which are already too great, are increased and matters are made worse instead of better. Likewise in dealing with over exposure the rapid appearance of the image and the quick growth of density lead one to remove the plate before the proper stage of contrast has been reached. This again is just the reverse of what should be done as it lessens the contrasts, which owing to over exposure are already insufficient.

While a large number of experienced photographers develop by inspection, with results in every way comparable to those obtainable by any other method, nevertheless, it must be said that it is a more or less haphazard, unsystematic method of working which lacks the precision which is required of a process as important as that of development. While it is true that none of the commonly used methods of development are theoretically more than approximations to the required condition, nevertheless we think that it may be said that either the factorial or thermo methods are more certain and less subject to error than is development by inspection. It is at any rate not a method for the beginner, nor even for the advanced worker who works only at intervals and under varying conditions. For these, either the factorial or thermo methods are to be preferred.

The Watkins System of Factorial Development.—Considerable information concerning the velocity of development is supplied by the time of appearance of the image. In 1893 Mr. Alfred Watkins, the well-known authority on exposure and development, found that the time of appearance is an indication of the speed of development and that any variation in the dilution of the developing solution, the temperature, or the alkali, affects the time required to reach a given density, or value of gamma, in the same way that it affects the appearance of the image. In other words

$$T_D = WT_A,$$

where T_D is the time for density, D, T_A the time of appearance and W is a constant. It is this constant, W, which is termed the *Watkins factor*.

With any given developing agent the factor depends upon the degree of contrast or gamma which it is desired to reach. Once the factor is found for any given set of conditions the time of development can always be readily determined by multiplying the time of appearance by the proper factor.

What Determines the Factor.—The factor is dependent principally upon the developing agent. The presence of a soluble bromide, however, has a decided effect. The factor does not change for different plates, except in the case of a very few plates containing a much larger amount of iodide than usual. Neither is it altered by variations in the amount of the alkali nor by the dilution of the solution, except in the case of pyro and amidol. With these the factor varies with the strength of the solution. Within the range of temperatures generally utilized for development, there is comparatively little alteration in the Watkins factor with most developing agents. There is a slight variation, however, with some agents at extreme temperatures.

The following factors are suggested for a start, but the experience of the photographer and the requirements of his particular printing medium may lead him to think an alteration of the factor desirable. If after the first few trials, using the factors as given, the negatives indicate that greater contrast would be desirable, the factor should be increased, while if the negatives show too much contrast a lower factor should be used in the future. Hence the following factors should not be considered as final but on the contrary as suggestive only; to be used until experience shows a higher or lower factor to be better suited to the requirements of the individual.

Adurol	5	Certinal	30
Pyrocatechin	10	Amidol (2 gr. to the oz.)	18
Hydrochinon (min-KBr)	5	Rodinal	40
Hydrochinon (max-KBr)	4½	Ortol	10
Eikonogen	9	Edinol	20
Glycin (Carb. Soda)	8	Metol	30
Glycin (Carb. Potash)	12	Quinomet	30
Paramidophenol	16		

Pyro-soda

Without Potassium Bromide	Factor	With Potassium bromide	Factor
1 gr. to the oz.	18	¼ gr. KBr per oz.	9
2 gr. to the oz.	12	½ gr. KBr per oz.	5
3 gr. to the oz.	10	¾ gr. KBr per oz.	4½
4 gr. to the oz.	8	1 gr. KBr per oz.	4

Pyro-acetone—about double the above.

The factor of a combination developer containing two or more developing agents depends upon the proportions of the various agents to one another. If in equal parts, the factor is simply the average of the factors of the two agents. But if, for instance, the developer contains 2 parts hydrochinon to one of metol (3 parts in all) the factor is put down for all three parts and the sum divided by 3, or

$$\frac{5 + 5 + 30}{3} = 13\tfrac{1}{3}.$$

A combination developer containing pyro, however, does not conform to this rule and its factor must be determined by trial.

Accuracy of the Factorial System.—The principle upon which the factorial method is based is open to, and has been made the subject of, some criticism. Although careful investigation has shown that there is not in all cases that definite and fixed relationship between the time of appearance and the time of development for a given gamma as assumed by the Watkins factorial method, in the vast majority of cases the departure from this relationship is comparatively small and without any particular significance in practical work. There are in all three sources of error in the factorial system. These are as follows:

1. The difficulty in observing the correct time of appearance.
2. Occasional variations in the Watkins factor.
3. Variation of the time of appearance with the degree of exposure.

Several years ago Mr. A. Lockett conducted a number of investigations with six different persons to determine the seriousness of the errors in observing the time of appearance and concluded that:

1. What is called the personal equation in factorial development is of comparatively small importance, provided average care be used: being, in fact, much less likely to cause variation in results than with the old system of judging development by inspection.

2. Although a developer with a medium factor is probably preferable, there is practically no more fear of variable results with a large developing factor than with a small one—given reasonable care in observing the time of appearance.

3. Some individuals are habitually quicker than others in observing the appearance of the image; but, as a rule, this variation is uniform and may be allowed for by an alteration in the factor.

4. Within limits a slight error in observing the appearance of the image has no serious results.[13]

Now that development may be conducted in bright yellow light, or even in white light in some cases, thanks to the introduction of satisfactory desensitizing agents, the difficulties in observing the appearance of the image are removed and errors from this source are practically negligible. Desensitizing also removes another objection to the factorial system which was formerly of some importance. To observe the appearance of the image it was necessary to hold the dish close to the safelight and this greatly increased the danger of fog, particularly with color sensitive plates. All danger of fog from this source has, of course, been completely removed by desensitizing.

Much has been made by critics of the factorial system of the fact that the Watkins factor is subject to variation with different batches of the same plate and developing agent. While it may be true that such inconstancy in the Watkins factor occurs, it is only fair to say that in practice it is negligible and cannot be said to constitute a serious objection to the method.

The variation of the time of appearance with the degree of exposure is the weakest point of the factorial system. It is a matter of common knowledge that the time of appearance of the image in development is greater for under exposure and less for over exposure than for normal exposure. Since the time of appearance is directly proportional to the time of development by the factorial method, the time of development varies with the time of appearance. Consequently under exposures receive longer and over exposures shorter development than do normal exposures. As we have already seen, the time of development required to reach a given stage of contrast (γ) is independent of the time of exposure and hence under and over exposures should receive the same development as a normal exposure. Mr. Watkins advises as a means of lessening this source of error that several plates be developed at one time and the mean time of appearance taken. This is of course better than taking the time of appearance from a single exposure, but is at best only an approximation.

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[13] *Brit. J. Phot.*, 1906, 53, 464.

With plates which have received correct, or nearly correct, exposure factorial development is perfectly satisfactory and in some respects the most desirable method of development. Where correct exposure cannot be ensured, thermo development is to be preferred.

Thermo Development.—Development for a fixed time at a certain temperature was indicated by Hurter and Driffield in their first paper "Photochemical Investigations, etc.," before the Liverpool Section of the Society of Industrial Chemistry in 1892.

Mees and Sheppard, in a number of papers constituting in general a comprehensive review of the work of Hurter and Driffield in sensitometry and other allied problems relating to photographic theory, developed the mathematical relations between the time of development and gamma and the effect of the velocity constant of development (k) and maximum contrast, or gamma$_{infinity}$ on the time of development. Their investigations, besides extending our knowledge of the physicochemical factors in development, established accurate means of calculating the time of development for any desired gamma.

In 1903, Houdaille made the first quantitative observations on the rate of development at different temperatures. Two years later Ferguson and Howard gave particulars of a method of calculating the times of development at different temperatures and a year later the former published the results of a more complete investigation with mathematical formulæ for the calculation of the temperature coefficient.

The fundamentals of thermo development were now established, but it remained for Mr. Alfred Watkins, by his carefully compiled tables of the developing speeds of commercial plates and times of development at various temperatures adapted for use with any plate, to eliminate the necessity for the individual to calculate by an exacting laboratory test the constants for his own particular case. This handicap removed, thermo development became exceedingly simple and was widely adopted both by amateurs and professionals.

The Watkins System of Thermo Development.—The time of development required to reach a given stage of contrast, or gamma, depends upon:

1. The maximum contrast obtainable (γ_∞).
2. The velocity constant of development (k).
3. The temperature coefficient (T.C.).

Methods of calculating these factors and from them the time of development at various temperatures for any given gamma have already been given (pages 262 to 265) and from these the student can determine for himself the proper times of development at various temperatures with the particular plate and developer to which he is accustomed. However, as many have neither the facilities nor the inclination to make these calculations for themselves and yet desire to use the thermo method, in the following pages we will reproduce Watkins' tables of commercial plates and times of development.

The Watkins system takes into consideration the developing speed of the plate, the developer and the effect of temperature on the rate of development. All commercial plates are divided into eight classes according to the time required to reach a gamma of 0.9. These classes are termed Very Very Quick, Very Quick, Quick, Medium Quick, Medium, Medium Slow, Slow, Very Slow, and designated by the letters VVQ, VQ, Q, MQ, M, MS, S, and VS respectively. Instead of varying the time of development for each class of plates, the necessary allowance is made by altering the dilution of the developer so that at a normal temperature of 66° F. plates of each class require the same time of development. This reduces the number of scales of times of development to two—one for tray and one for tank development—and considerably simplifies the system. Six different developers are adapted for use with the tables which will be given shortly. These include pyro-soda, metol-quinone, Rodinal, Azol, Citol and Certinal.

Developing Speeds of Commercial Plates.—

Barnet—	
Ultra Rapid	S
Super Speed Ortho	S
Studio 500	MS
Press	VS
Studio 400	MS
Portrait Isonon	M
Anchor	MQ
Commercial	MQ
Medium Iso	M
Commercial Isonon	M
Contrast	Q

Studio Ortho 400	M
Red Seal	M
Self Screen Ortho	MQ
Red Diamond	MS
Special Rapid	MS
Ordinary	MQ
Cramer—	
Hi-Speed	VS
Speed-O-Krome	S
Crown	S
Banner-X	S
Instantaneous Iso	M
Cine Panchromatic	MS
Positive Cine	MQ
Ensign—	
Film	MS
Gem—	
Gold Label	S
Salon Xpres	VS
Salon	S
Salon Isochromatic	Q
Portrait	S
Colour Screen	M
Meteor	VQ
Isochromatic	M
Panchromatic Tricol	Q
Universal	M
Slow Universal	MQ
Gevaert—	
Sensima	VS
Ultra Rapid	MS
Orthochrome	MS
Special Rapid	S
Anti-Halo	MS
Filtered Ortho	MQ
Ortho Anti-Halo	MS
Cine Film	MQ
Hammer—	
Special Extra Fast	MS
Extra Fast	MS
Slow	Q
Commercial Ortho	Q
Ortho Extra Fast	MS
Ortho Slow	Q
Ortho Double-Coated	MS
Aurora Non-Halation	MS
Photo Postal	VVQ
Postal	Q
Double-coated according to brand	
Eastman Film—	
Portrait Par Speed	MS
Super Speed	VS
Commercial	MS
Commercial Ortho	MS
Panchromatic	MQ
Non-Curling Speed	S
Premo Speed	S
Cine Super Speed	VS
Cine Ordinary	S
Screened Chromatic	Q
Empress	Q
Rapid Process Panchromatic	VVQ
Ordinary	Q
Zenith Extra Sensitive Film	VS
Zenith Film	MS
Special Rapid Film	MS
Empress Film	VQ
Illingworth—	
Studio Extra Fast	VS
Fleet	MS
High Rapidity	S
Ortho Fast	MS
Studio Ortho Fast	M
Ultra Rapid	S
Special Rapid	S
Non Screen	MQ
Medium	MQ
Ortho Medium	MQ
Ordinary	MQ
Imperial—	
Eclipse	S
Flashlight	S
Special Sensitive	S
S. S. Ortho	MS
Panchromatic A	Q
Panchromatic B	VQ
Special Rapid	MS
Special Rapid Ortho	MS
Non-Filter Ortho	Q
Sovereign	M
Ordinary	MQ
Fine Grain Ordinary	VVQ
Landscape	Q
Film	MS

Ilford—	
Zenith 650	VS
Zenith 400	S
Press	VS
Monarch	VS
Special Rapid Panchromatic	MQ
Most Rapid Versatile	MS
Versatile Ortho	Q
Special Rapid	M
Rapid Chromatic	Q
King's Own	M
Versatile Rapid	M
Chromatic	M Q
Plavik Film	MQ
Cine	M
N. C. Speed	S
Sigma Ortho	S
Marion—	
Iso Record	Q
Record	S
Panchromatic	VS
Brilliant	MQ
P. S.	MS
Instantaneous	MS
Iso	M
Portrait	M
W. B.	M
Ordinary	MQ
Stanley—	
50	M
Commercial	Q
Wellington—	
Super Xtreme	VS
Xtreme	VS
Studio Anti-Screen	S
Press	VS
Special Extra Speedy	S
Extra Speedy	MS
Speedy Portrait	MS
Speedy	S
Anti-Screen	M
Iso Speedy	M
Ordinary	Q
Film	M
Lumière & Jougla—	
Maxima	M
Portrait Instantanee	M
Grands Instantanee	MQ
Ortho, Yellow and Green	Q
Ortho, Yellow and Red	Q
Intensive	M
Panchromatic	VQ
Instantanee	MQ
Extra Rapide	MQ
Film	MS
Reproduction	MQ
Panchromatic Procede	Q
Paget—	
XX	MS
XXX	MS
Process Panchromatic	M
S F. Orthochromatic	S
Special Rapid	S
Professional Medium	S
Portrait	S
Professional Extra Rapid	VS
Extra Special Rapid R.	VS
Ordinary Panchromatic	MS
Hurricane	S
Extra Special Rapid Ortho	S
Seed—	
Graflex	VS
Gilt Edge	VS
Color Value	M
L Ortho	M
26 X	M
Non-Halation L Ortho	MS
Tropical	M
Panchromatic	Q
23	Q
Process	Q
Standard—	
Extra Imperial	M
Orthonon	M
Polychrome	M
Wratten & Wainwright—	
Panchromatic	Q
Process Panchromatic	Q
Wratten M (backed)	Q

Developers.—Thermo Pyro-Soda:

A. Potassium metabisulphite	80 gr.	16.7	gm.
Pyro	160 gr.	35.5	gm.
Sodium sulphite (dry)	1 oz.	91.2	gm.
Water to make	10 oz.	1000	cc.
B. Sodium carbonate (dry)	2 oz.	182.4	gm.
Potassium bromide	40 gr.	8.35	gm.
Water to make	10 oz.	1000	cc.

Thermo-Metol Hydrochinon (as modified by F. R. Fraprie):

A. Potassium metabisulphite	60 gr.	6.25	gm.
Metol	30 gr.	3.125	gm.
Hydrochinon	90 gr.	9.375	gm.
Water to make	20 oz.	1000	cc.
B. Sodium sulphite (dry)	1 oz.	45.6	gm.
Sodium carbonate (dry)	1½ oz.	78	gm.
Water to make	20 oz.	1000	cc.

Dilution of developer.	VVQ	VQ	Q	MQ	M	MS	S	VS
Pyro-Soda	1	1⅓	1¾	2¼	3	4	5	6¾
Metol-Hydrochinon	1½	2	2⅔	3½	4½	6	8	10

drams of each stock to be diluted to make a total of 3 ounces for tray or 10 ounces for tank.

Rodinal, Azol, Citol, Certinal	20	26	35	45	60	80	105	135

minims solution to be made to a total of 3 ounces for tray or 9 ounces for tank. In metric measure

	VVQ	VQ	Q	MQ	M	MS	S	VS	
M–Q	30	41	55	73	94	125	165	210	for tray
	9	12	16	22	28	38	50	65	for tank
Pyro-soda	41	55	73	94	125	165	210	280	for tray
	12	16	22	28	38	50	65	84	for tank
Certinal, Rodinal, Azol, Victol	13	17	23	30	40	53	70	90	for tray
	4.3	5.75	7.75	10	13	18	24	30	for tank

The above figures are cc. and are to be diluted to a total volume of 1000 cc.

Instructions.—The use of the system is simplicity itself. Determine by reference to the table the developing speed of the plate or film and mix the developer as directed for that class, using water which has attained the same temperature as the room in which development is conducted. This avoids any variation in the temperature of the solution during development. The temperature of the developer having been determined, find the time of development by reference to the table of temperatures. In a safelight, or total darkness, flow the plate with the developer, or if using a tank, immerse the cage containing the plates in the solution and start the darkroom clock. If a timer is not available an ordinary watch may be used. As there is no necessity whatsoever for observing the plate during development, the tray may be covered with a light-excluding cover and the white light turned on in order to observe the time at which development started. When the time of development has expired, turn out the white light and remove the plate.

TABLE OF TIME OF DEVELOPMENT AT VARIOUS TEMPERATURES

Degrees Fahr.	Degrees Cent. to nearest half	Time in tray	Time for tank
80	27.0	3¼	12
78	26.0	3½	13
76	24.5	3¾	14
74	23.5	4	15
72	22.5	4¼	16
70	21	4½	17
68	20	5	18¼
66	19	5¼	19½
64	18	5¾	21
62	17	6¼	22½
60	16	6½	24
58	14.5	7	26
56	13.5	7½	28
54	12.5	8	30
52	11.5	8½	32
50	10	9¼	34
48	9	10	37
46	8	10¾	40
44	7	11½	43
42	6	12¼	46
40	4.5	13¼	49

If the first trial does not produce a negative having the proper amount of contrast to suit your individual case, classify the plate one class nearer VS for more or one class towards VVQ for less contrast.

The Thermo Method with Glycin.—The following formula and system for the use of glycin according to the Watkins thermo method is due to Mr. Arthur Purdon and was published in *American Photography.*

THERMO-GLYCIN

Stock Solution

Water to make	500 cc. or	10 oz.
Potassium carbonate (dry)	30 gm. or	280 gr.
Sodium sulphite (dry)	10 gm. or	90 gr.
Glycin	15 gm. or	140 gr.

Plate Class	Cc. of Stock to be made up to 300 cc. for Tank or 90 cc. for Tray	Drams of Stock to be made up to 10 oz. for Tank or 3 oz. for Tray
VVQ	6	1½
VQ	7½	2
Q	10½	2⅔
MQ	13½	3½
M	18	4½
MS	24	6
S	30	8
VS	40½	10

Temperature—Time Table

Temp. Degrees Fahr.	Time Minutes Tank	Time Minutes and Seconds Tray
80	10	2 M. 50 S.
78	11⅛	3 M. 10 S.
76	12⅜	3 M. 30 S.
74	13½	3 M. 50 S.
72	14¾	4 M. 13 S.
70	16	4 M. 35 S.
68	17	5 M.
66	18⅝	5 M. 20 S.
64	20	5 M. 36 S.
62	21⅜	6 M.

Temperature coefficient, 2.2.

The Efficiency of Time Development.—As has been stated previously the time of development depends upon

1. The maximum contrast of the plate (γ_∞).
2. The velocity constant of development (k).
3. The temperature coefficient (T.C.).

The application of any rules found for one particular batch of a particular plate to a different batch of the same plate must depend on these factors remaining constant. As a matter of fact, however, comparatively large and unordered variations in these factors occur with different batches of the same plate regardless of the extreme care taken by the manufacturers to secure uniformity in their products. The maximum contrast (γ_∞) of a plate is reasonably constant from batch to batch, but varying circumstances ofttimes introduce considerable variation, amounting in some cases to 30 or 40 per cent. The velocity constant of development varies considerably with different batches of the same plate. This is due largely to the rate at which the plates are dried, which even in the elaborate systems used by manufacturers is subject to some variation. In addition an alteration in the character of the gelatine used for a batch of plates may seriously alter the factor. Furthermore, as has already been mentioned, the temperature coefficient is not independent of the plate, consequently a table of times of development at various temperatures which is applicable to one plate may not be applicable to another which develops at the same rate at a normal temperature. The temperature coefficient, however, varies but slightly with different batches of the same plate.

Therefore it appears that thermo development can only be accurately conducted when the values for the controlling factors (γ_∞ and k) are known for each batch of plates. Unfortunately manufacturers have not yet seen their way to do this, nor, except in a few isolated cases, have they adopted the plan of indicating the time of development for each batch of plates. This has been done by a few manufacturers in the case of panchromatic plates, but with the vast majority of plates no information is given of the way, nor the extent, to which they differ from previous batches of the same plate. It would be a decided step in advance if the manufacturers could be induced to indicate for each batch of plates the time of development required to reach gammas of say 0.8, 1, and 1.3 with the developers regularly advised for use with the plate.

Nevertheless where such information is lacking and development is alike for all batches of the same plate, thermo development is a singularly uniform process which yields a surprisingly high percentage of satisfactory results. Such errors as may occur from variations in the governing factors are comparatively small and seldom sufficient to be of serious consequence. It is perhaps this more than anything else which has prevented the individual testing of each batch of plates by the manufacturer, who holds, and it must be admitted with a show of reason, that such variations as do occur are not of sufficient importance to warrant the labor and expense involved in the testing of each individual batch of plates. Nevertheless, in spite of the extreme care taken by manufacturers to keep their product uniform, considerable variations between different batches of plates occur occasionally and consequently laboratory testing of each batch of plates by the manufacturer would be a distinct gain in scientific accuracy and thoroughness.

Development at High Temperatures.—The important thing to avoid in the developing of plates and film at high temperatures is to prevent undue swelling of the gelatine in the warm solutions. The actual hardening of the gelatine by a preliminary bath of formaline or a combination of formaline and sodium sulphate as in the Ilford tropical hardner (B. P. 128,337 of 1918) is essential only at extremely high temperature. When the temperature of the solutions does not exceed 90° Fahrenheit it is sufficient to simply prevent undue swelling of the gelatine during development. If a rapid developer is used so that development is complete within three to four minutes, abnormal swelling of the gelatine may be prevented by the addition of one part of sodium sulphate to each ten parts of the developing solution. Sodium sulphate does not harden gelatine, but only depresses swelling, consequently after development the gelatine must be permanently hardened with either a ten per cent solution of formaline, or with alum. If alum is used, the gelatine will be more thoroughly hardened if sodium sulphate is added to the alum solution; due to the fact that the sodium sulphate prevents swelling while the alum is hardening. The following formula is suitable:

Sodium sulphate (crystals)	1 lb.	120 gm.
Potassium chrome alum	3.84 lb.	30 gm.
Water	1 gal.	1000 cc.

The film or plate should be rinsed briefly after removal from the developer and before being placed in the hardening bath. To prevent the formation of blisters and alum stains, sensitive material should be kept on the move for about one half minute after immersion in the alum solution. If this is not done, stains will be formed on the surface of the gelatine which are very difficult to remove. This will occur also if the bath has been overworked or is old, and a fresh bath should be prepared at least once a day as solutions of chrome alum do not keep at high temperature.

After three minutes immersion in the hardening bath, the plate or film may be transferred to the usual and fixing bath for fixing. After fixing it may be washed for five minutes in running water up to 90° Fahrenheit without danger.

General Reference Works

Blech—Stand-Entwicklung.
Brown—Developers and Development.
Hübl—Entwicklung der photographische Bromsilbergelatineplatten. 1922.
Lüppo-Cramer—Negativ Entwicklung Bei Hellem Lichte. 1922.
Renger-Patzsch—Die Stand-Entwicklung. 1920.
Seyewetz—Le Negatif en Photographie. 1922.
Watkins—Watkins' Manual. 1918.
Watkins—Photography—Its Principles and Applications. 1927.
———Modern Methods of Development. Photominiature, No. 139.

CHAPTER XIV

FIXING AND WASHING

The Action of Sodium Thiosulphate on Silver Halide.—Only a few substances are capable of dissolving the silver halides and a still smaller number are of practical value for fixing. Of these only two are of sufficient importance to justify mention. These are potassium cyanide and sodium thiosulphate, commonly termed sodium hyposulphite or hypo, but the hyposulphite is an entirely distinct chemical. Potassium cyanide is much too powerful for use with gelatinobromide emulsion as it tends to dissolve silver and thus weaken the lower deposits of the negative and for this reason sodium thiosulphate, which is free from such action, is generally used. The use of the thiosulphates is due to Sir John Herschel who drew attention to their solvent action on the silver halides in a paper in the *Edinburgh Philosophical Journal* in 1819.[1]

The precise chemical reactions involved in the fixing process are still somewhat obscure. According to the earlier theories, based upon the compounds isolated by Herschel,[2] the thiosulphates dissolve silver halide by uniting with it to form a compound of silver-disodium thiosulphate according to the reaction:

(1) $2AgBr + Na_2S_2O_3 = 2NaBr + Ag_2S_2O_3$
(silver thiosulphate),

(2) $Ag_2S_2O_3 + Na_2S_2O_3 = Ag_2S_2O_3 \cdot Na_2S_2O_3$
(silver-monosodium-thiosulphate),

(3) $Ag_2S_2O_3 \cdot Na_2S_2O_3 + Na_2S_2O_3 = Ag_2S_2O_3 \cdot 2Na_2S_2O_3$
(silver-disodium-thiosulphate).

The silver thiosulphate formed in equation (1) is supposed to be insoluble in water but soluble in sodium thiosulphate, being transformed into silver-monosodium-thiosulphate (equation (2)) which, like the first salt, is insoluble in water but soluble in sodium thiosulphate, in which it is converted into silver-disodium-thiosulphate (equation (3)), which is soluble in water.

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[1] *Edinburgh Phil. Journ.*, vol. I, pp. 8, 396.

[2] *Ibid.*

Baines,[3] as a result of a later investigation of the subject, concludes that it is extremely doubtful that reaction (1) actually takes place, and as all attempts to prepare the compound $Ag_2S_2O_3 \cdot 2Na_2S_2O_3$ failed, but instead a compound having the formula $Na_5Ag_3(S_2O_3)_4 \cdot 3H_2O$ was found, the following equations are probably more accurate representations of the reactions which take place in fixing:

1. $AgBr + Na_2S_2O_3 = NaBr + NaAgS_2O_3$,
2. $3NaAgS_2O_3 + Na_2S_2O_3 = Na_5Ag_3(S_2O_3)_4$.

The removal of the unaltered silver halide may therefore be considered to consist of two operations: (1) the conversion of the insoluble halide into soluble double salts by sodium thiosulphate and (2) the removal of this double salt by washing in water.

The Mechanism of Fixing.—The mechanism of fixing has been studied by Sheppard and Mees[4] and by Warwick[5] who by very different experimental methods reached substantially the same conclusions. Without discussing in detail the experimental methods of these investigators, for which purpose the original papers should be consulted, we propose to deal briefly with their principal conclusions.

The fixing bath dissolves per unit of time a constant fraction of the mass of silver bromide existing in the film at the origin of the interval of time considered. The amount of silver bromide left in the negative at any time can therefore be expressed mathematically as

$$x = a(I—k)^n,$$

where a is the original amount of silver bromide in the negative; k, the fraction dissolved per unit time; x, the amount remaining after n units of time. The value of this fraction, which may be termed the *velocity constant of fixation,* depends upon the temperature and the concentration of the fixing bath and is independent of the amount of silver bromide in the film, the quality of the gelatine, or previous tanning of the film by formaline or similar agents but is always greater, under identical conditions, with silver chloride emulsions than with silver bromide emulsions and for the same silver halide is more rapid with a decrease in the size of grain.

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[3] *Phot. J.*, 1929, **69**, 314.

[4] Investigations, *Phot. J.*, 1906, **46**, 235.

[5] *Amer. Phot.*, 1917, pp. 585, 639.

The simplest explanation of the known facts is that the rate of fixation is determined primarily by the penetration of the sodium thiosulphate through the film, the chemical action being rapid compared with this.

Influence of the Concentration of Sodium Thiosulphate and Temperature on the Time of Fixation.—The investigations on the theory of fixation by Sheppard and Mees were concerned primarily with the velocity rather than the time of fixing which last is of more interest to the practical photographer. The influence of temperature and the concentration of the fixing bath on the time of fixing, or more exactly the semi-total time, or the time of clearance, was carefully studied by C. Welborne Piper in 1913 and the results published in the *British Journal* of the same year.[6]

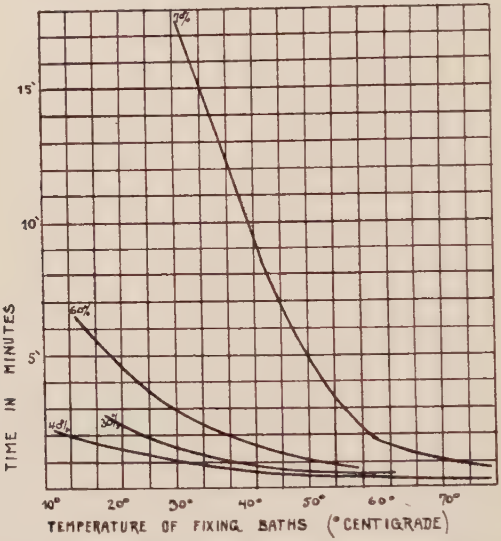

FIG. 151. Influence of Temperature on Time of Fixation

The results obtained for the effect of temperature on the time of fixing were plotted in the form of a series of curves (Fig. 151). These show that the time of fixing varies approximately in inverse ratio to the temperature so long as small variations of temperature alone are considered. The curves also show that the effect of temperature varies greatly with the concentration of the fixing bath, a bath of 40 per cent showing less variation with a given range of temperature than those of lower or higher concentration. The effect of

[6] *Brit. J. Phot.,* 1913, 60, 59.

temperature is especially noticeable with very strong solutions. Thus from the curve representing a concentration of 70 per cent it appears that at a temperature of 20° C. several hours would be required for the clearance of the film and according to Piper there is doubt that complete fixing would ever take place under such conditions. With high temperatures the differences in the time of fixing for baths of various concentrations become less noticeable and it is probable that at a sufficiently high temperature the time of fixation would be the same for all baths regardless of concentration, since all the curves are of similar character and tend to meet in a point to the right of the graph. This is a matter difficult to prove or disprove experimentally owing to the softening of the film at the high temperatures involved.

Figure 152, from Piper's paper, gives the curves for the effect of varying concentrations at the same temperature, the time in minutes

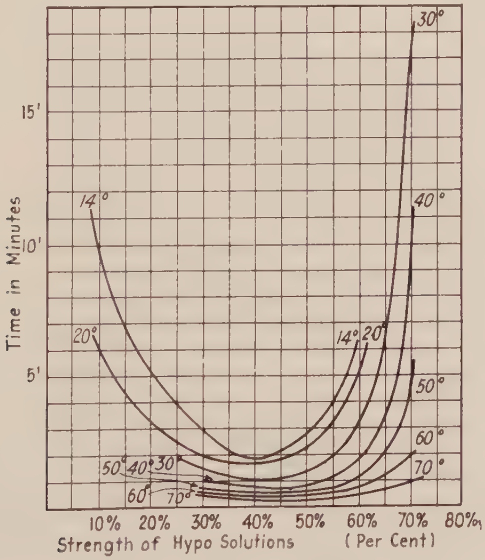

Fig. 152. Influence of Concentration of Hypo on Time of Fixation

being plotted against the concentration and the curves representing the results obtained for temperatures of 14, 20, 30, 40, 50, 60, and 70° C. (57, 68, 86, 104, 122, 140, 158° F.).

Influence of Ammonium Chloride on the Rapidity of Fixation.—Ammonium thiosulphate was recommended as a fixing agent in place of the commonly used sodium salt by Spiller in 1868. Although it is much more rapid in action than sodium thiosulphate, it does not equal the latter in general adaptability and owing to this, and to its higher cost, it has never been widely used.

The investigations of C. Welborne Piper[7] have well established the fact that for each thiosulphate the rate of fixation is more rapid at a certain concentration which is variable with each of the three thiosulphate salts investigated. With ammonium thiosulphate and sodium thiosulphate the concentrations at which the maximum rapidity of fixing is secured are 15 and 40 per cent respectively. At 15 per cent, ammonium thiosulphate is approximately twice as fast as the sodium salt at 40 per cent. The rate of fixation is practically identical at a concentration of 33 per cent. Above this point the sodium salt is the more rapid while at lower concentrations the ammonium salt is the more rapid.

The rapidity of fixing is considerably increased by the addition of ammonium chloride to the solution of sodium thiosulphate. The increase in rapidity is probably due to the partial conversion of the sodium thiosulphate into the corresponding ammonium salt, but apparently some undetermined factor also plays a part in the reaction, since the reaction is not as fast when the proportion of ammonium chloride is sufficient to completely convert the sodium salt to the corresponding thiosulphate as when a lesser amount is used. Thus the increase in rapidity of fixing cannot be due entirely to the conversion of the sodium thiosulphate into the ammonium salt.

The effect of adding various amounts of ammonium chloride to solutions of sodium thiosulphate at various concentrations was carefully investigated by Lumière and Seyewetz in 1908[8] and by C. Welborne Piper in 1914. The results obtained by the latter investigator are shown in Fig. 153. From this it will be observed that for each concentration of thiosulphate there is a certain definite proportion of ammonium chloride which produces the maximum degree of acceleration. On increasing the proportion of ammonium chloride beyond the optimum point, the acceleration diminishes, the rate of diminution increasing with the concentration of sodium thiosulphate. The chart does not show the effect of adding ammonium chloride to a bath of sodium thiosulphate above 40 per cent for, since no acceleration takes place under these conditions, the result would be of no practical value.

[7] *Brit. J. Phot.*, 1914, **61**, 193, 437, 458, 511.

[8] *Bull. Soc. franc. Phot.*, 1908, p. 217.

The maximum rapidity of fixing is secured by the use of a 15 per cent solution of sodium thiosulphate containing ¼ of its weight of ammonium chloride. The following formula is suitable for a rapid fixing bath for use in newspaper and similar work:

Sodium thiosulphate ("hypo")	15 oz.		150 gm.
Ammonium chloride	4 oz.	50 gr.	37.5 gm.
Water to make	100 oz.		1000 cc.

The double salts of silver formed in the fixing bath containing ammonium chloride were shown to be less stable than those formed in a plain bath of thiosulphate by Lumière and Seyewetz, consequently rapid fixing baths containing ammonium chloride are more rapidly exhausted than plain solutions of sodium thiosulphate and cannot be used for as many plates or films.

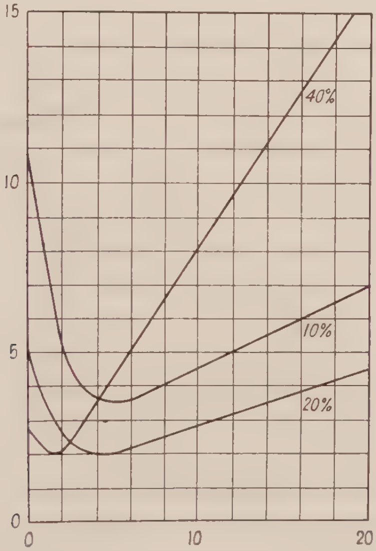

Fig. 153. Influence of Ammonium Chloride on the Time of Fixation

The addition of free ammonia increases the rapidity of fixing in much the same way as ammonium chloride. Owing, however, to its disagreeable odor and its tendency to produce a type of fog known as "dichroic" it is never used in practice.

When are Plates Fixed?—The time of fixation is not as important in general photographic practice as an accurate means of determining when fixation is complete. A rule found in many textbooks directs that the negative be left in the fixing solution as long again as is required for the disappearance of the opalescent coating from the back of the plate. Recent investigations by Lumière and Seyewetz [9] have shown that in a fresh fixing bath this extra time is unnecessary as fixation is complete when the opalescent coating has completely disappeared from the back. When the fixing bath contains less than 2 per cent of silver salts dissolved from previously fixed plates, fixing is still completed when the opalescent coating disappears, but when the amount of silver salts is in excess of 2 per cent, or 20 grams per liter (96 grains to 10 ounces), the removal of unaltered silver salts is incomplete and *the residual salts are not removed by prolonging the immersion of the plate in the solution.* However, if the plate is then transferred to a fresh bath all residual silver salts will be removed. The use of two fixing baths is therefore advisable unless one cares to make up a fresh fixing bath for each batch of negatives and discards it immediately after use. In the first case, the first bath is used nearly to the point of exhaustion, the negatives being transferred from this solution to a fresh one in which they are allowed to remain for five minutes. The first bath is then discarded and its place taken by the second bath which is in turn replaced by a freshly prepared solution. When the plate is allowed to remain in the first bath until completely cleared, then transferred to the second bath for five minutes, there is no danger of imperfect fixation, hence this plan is strongly recommended in preference to the somewhat haphazard methods generally advised.

Exhaustion of the Fixing Bath.—While it would be well if photographers could be induced to use a small quantity of a fresh fixing bath for each plate or film, discarding the bath immediately after use, this is seldom, if ever, done in practice, the same bath being used continuously until its slow action indicates that its fixing power is exhausted. A knowledge of the number of plates, films, or prints which can be fixed in a given volume of bath is thus of considerable practical value, as it enables one to determine when the bath is exhausted and prevents the risk of imperfect fixation owing to the use of an overworked fixing bath. It is evident that the number of plates which may with safety be fixed in any given quantity and strength of bath is dependent upon the amount of the various halides which can be completely dissolved by a given amount of sodium thiosulphate. The order of solubility of the three halides is chloride, bromide, iodide. Determinations of the solubilities of the halides in hypo have been made by Valenta, Lumière and Seyewetz, Strauss, and by Lehrmann and Busch.[10]

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[9] *Brit. J. Phot.,* 1924, 71, 172.

There are serious discrepancies in the results and further work is desirable. The earlier investigations, conducted on a basis of silver bromide, indicated that a fixing bath could be regarded as having been exhausted when the silver content equalled 2 per cent. In view of later work, in which the influence on fixation of the small amounts of silver iodide present in most emulsions has been more thoroughly investigated, this figure appears to be much too high and according to the latest determinations, the practical limit seems to be from 0.6–0.7 per cent. With an average single-coated plate, this point is reached, approximately, when a 3¼ × 4¼ plate is fixed in one ounce of 10 per cent hypo. A 20 per cent solution of hypo has greater fixing capacity but not in direct ratio to the concentration.

The point at which the fixing bath is exhausted may be determined with sufficient accuracy for all practical purposes by immersing a strip of film or bromide paper in the bath until clear, washing for several minutes under the tap followed by immersion in a 1 per cent solution of sodium sulphide. The formation of a brown coloration indicates that the soluble halides have not been completely removed by the fixing bath and that a fresh bath should be substituted.

The Fixation of Prints.—Warwick in 1917[11] and Lumière and Seyewetz again in 1924 have called attention to the very short time required for the fixation of bromide and gaslight prints. Both investigators have shown that fixation is a matter of only a few seconds, being approximately twenty to thirty seconds in 25 per cent thiosulphate and only slightly greater in a fixing bath containing bisulphite. The rapid fixation of paper prints is doubtless due to the porous nature of the support which allows the reaction to proceed from both sides of the emulsion.

It does not follow from the above, however, that such short periods of fixation are sufficient under the conditions of ordinary practice. In the above experiments the prints were separately fixed in fresh fixing solutions, a totally different state of affairs from that presented in practical work where large numbers of prints are added to the same solution. When dozens of prints are being treated at the same time, the time required for fixing is necessarily dependent upon the time which the print is exposed to the action of the fixing bath. This is a matter of moving the prints around in the bath individually so that each becomes completely exposed to the solution. It is evident that under such conditions the time required for perfect fixation will be much greater than those advised by Warwick and by Lumière and Seyewetz whose results were obtained with the use of individual fixing baths. On the other hand, the investigations show that in cases of rush work prints fixed individually in fresh baths for 20 to 30 seconds may be expected to be reasonably permanent.

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[10] *Berichte*, 1894, 103; *Bull. Soc. Franc.*, 1907, p. 104; *Phot. J.*, 1907, **47**, 129; *Phot. Ind.*, 1925, p. 881, 911; *Brit. J. Phot.*, 1927, **74**, 91, 105.

[11] *Amer. Phot.*, 1917, **11**, 639.

Plain Fixing Baths.—Although fixing is accomplished by thiosulphate alone, plain solutions of sodium thiosulphate are not much used in practical photography. This is due to the fact that the bath soon becomes discolored from the oxidized developer carried over on the surface of the negatives or prints fixed in it, and these oxidized products stain the negatives or prints. There is also a tendency in warm weather for the gelatine to swell excessively and become soft, producing frilling and any number of other troubles either while in the fixing bath itself or in the washing which follows. So far as the first objection is concerned staining of negatives or prints in a plain fixing bath may be largely prevented by immersing the negative or print in a weak bath of acid before placing in the fixing bath. Even when an acid fixing bath is used, the use of a weak acid bath prior to fixing prevents the bath from becoming discolored and lessens danger of stain. A weak bath of acetic acid (1 ounce 28 per cent acetic acid to 32 ounces of water) is to be recommended for this purpose, especially in the case of prints or when pyro is used as a developer.

From Piper's investigations on the influence of the concentration of the bath on the rapidity of fixation (pp. 340–341) it appears that if a bath giving the maximum speed of fixing and the least affected by temperature is desired this would be attained by the use of a solution of approximately 40 per cent. Various other considerations, however, intervene to make the employment of somewhat weaker solutions desirable. The abrupt transition from a strong thiosulphate solution to plain water produces a strong tension in the swollen film, which in hot weather gives rise to blisters and frilling and may even cause the whole film to leave the glass. On this account it is usual to employ a weaker solution of approximately 25 per cent, such as is obtained by adding 4 ounces of crystal thiosulphate to 16 ounces of water.

A convenient way of preparing plain fixing baths is to dissolve one pound of thiosulphate in about 16 ounces of warm water and when dissolved add cool water to 32 ounces. Every two ounces of this stock solution therefore contains 1 ounce of thiosulphate. To make up baths of different strengths it is diluted as follows:

Thiosulphate required for each 20 ounces of bath	Stock solution	Water
8 oz.	16	4
6	12	8
5	10	10
4	8	12
3	6	14
2	4	16

Acid Fixing Baths.—The addition of acid to the fixing bath for the purpose of combining the acid clearing bath frequently necessary for the removal of yellow oxidation stain when a plain fixing bath is used with the fixing bath itself and thus avoiding a separate operation was advised by Lanier in 1889. If an acid is added directly to a solution of thiosulphate the latter is decomposed and sulphur is precipitated. Lanier showed, however, that if a weak acid such as citric, acetic, formic or tartaric be used the precipitation of sulphur may be avoided by first combining the acid with a solution of sodium sulphite. When this is done the bath remains clear and there is no precipitation of sulphur unless there is an excess of acid present.

The most convenient method of preparing an acid fixing bath is by the use of sodium bisulphite which may be regarded as an acid sulphite, having the formula $NaHSO_3$. The following is an excellent formula:

Sodium thiosulphate ("hypo")	16 oz.	228 gm.
Sodium bisulphite	3 oz.	42 gm.
Water to make	64 oz.	1000 cc.

In large establishments the bisulphite may be made up as a 50 per cent stock solution. One part of this stock solution to each 20 parts of plain fixing bath will be in the correct proportion.

Potassium metabisulphite may be used in place of sodium bisulphite. The following formula is suitable:

Sodium thiosulphate	6 oz.	274 gm.
Potassium metabisulphite	½ oz.	22.5 gm.
Water to make	20 oz.	1000 cc.

A formula using citric acid and sodium sulphite originated by

Lanier was strongly advised by Sir William Abney. The formula follows:

Citric acid	¼ oz.	14.3 gm.
Sodium sulphite (dry)	¼ oz.	15.6 gm

Mix in 1 oz. (30 cc.) of water and add to

Sodium thiosulphate	4 oz.	228 gm.
Water to make	16 oz.	1000 cc.

Acid Fixing and Hardening Baths.—The third type of fixing bath, the acid fixing and hardening bath, is an acid bath to which an alum has been added to harden the gelatine and prevent softening and frilling with its attendant troubles in hot weather. The ingredients are generally an acid, sodium sulphite and alum and their function and formula are given in the following table: [12]

Constituent	Function	Formula
Sodium thiosulphate	Fixing agent proper, dissolves silver halide	$Na_2S_2O_3 \cdot 5H_2O$
Acid	Clearing agent, promotes swelling and increases the speed of fixing, reduces stain and coloration and regulates hardening agent (4)	H_2SO_3 (Sulphurous or organic acid)
Sulphite	Protects thiosulphate against decomposition by the acid. Anti-stain and anti-oxidant	Na_2SO_3 (Sodium sulphite)
Alum	Hardens gelatine, prevents frilling and softening	$K_2SO_4 \cdot Al_2(SO_4)_3$, (Potash alum) $K_2SO_4 \cdot Cr_2(SO_4)_3$ (Chrome alum)

The following formula using potassium alum is an excellent one for plates, films and papers:

Sodium thiosulphate ("hypo")	16 oz.	228 gm.
Water to make	64 oz.	1000 cc.

Dissolve separately and add to the above

Powdered alum	½ oz.	31 gm.
Acetic acid 28 per cent	3 oz.	186 cc.
Sodium sulphite (dry)	½ oz.	31 gm.
Water to make	5 oz.	312 cc.

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[12] The chemical theory of the acid fixing bath has been fully discussed in a paper by Sheppard Elliot and Sweet of the Eastman Research Laboratory in the Journal of the Franklin Institute for July, 1923, **195**, 45.

In mixing the last solution, or *hardener,* it is best to use two separate solutions. Dissolve the alum and sulphite each in a few ounces amount of water. Then add the acid to the sulphite solution, mix the two and add to the solution of thiosulphate. The hardener may be made up as a stock solution if desired as its keeping qualities are good.

Troubles with the Acid Fixing and Hardening Bath.—Since it represents a compromise between certain physico-chemical factors and practical conditions, the acid fixing and hardening bath is frequently a source of trouble owing to the fact that the exact balance between the various substances has not been secured when compounding the same.

If the bath turns milky on standing it is due to the acid attacking the thiosulphate and precipitating sulphur. This may result from three causes:

1. Too much acid, or too strong acid. Most formulas call for No. 8 or 28 per cent acetic acid and *not* the C.P. or Glacial.
2. Too little sulphite, bad sulphite, or high temperature of the solution.
3. Incorrect mixing. If the method advised above is followed there will be no trouble on this score.

If the milkiness disappears on standing it is due to the use of insufficient acid, or not enough hardener to overcome the alkalinity of the developer brought over on the surface of the prints or negatives.

If the bath does not harden this is due to the use of insufficient or impure alum, or to the fact that the bath is alkaline or neutral rather than acid. The hardening action of alum is due to aluminum sulphate and some grades do not have the proper proportion of this substance and accordingly must be used in greater quantity in order to secure equivalent action.

Extra Hardening Baths.—In very hot climates or other exceptional conditions, a bath having an even greater hardening action than that above may be an advantage and in such cases the following bath, as worked out by Mr. J. I. Crabtree of the Eastman Research Laboratory, will be found very satisfactory:

Sodium thiosulphate ("hypo")	5	oz.	228	gm.
Sodium sulphite (dry)	1	oz.	45.6	gm.
Formaline	2½	fl. oz.	125	cc.
Water to make	20	oz.	1000	cc.

Although this bath has not the keeping properties of the ordinary acid fixing and hardening bath it will keep for at least a week at a temperature of 100° F.

Owing to the irritating vapors of formaline, it is well to keep the bath in a tank with a tight fitting cover when not in use.

The Mechanism of Washing.—Following fixing, the next step is to remove the thiosulphate from the film. This is most generally effected by simple washing in water, although certain substances known as "hypo eliminators" are occasionally used.

The rate of the elimination of thiosulphate from photographic films of gelatine has been investigated a number of times: by Haddon and Grundy, Lumière and Seyewetz in 1910, Warwick in 1917, Elsden the same year and by Hickman and Spencer in 1922.[13]

It has been found that, in general, thiosulphate diffuses from the film expotentially with time as was stated by Mees and Sheppard in their *Investigations*. In other words the amount removed in a unit of time is proportionate to the concentration present at the beginning of the period. Thus if the original concentration is 10 grams and at the end of five minutes' washing, one half of this, or 5 grams, is removed, then, if the plate is changed to an equal volume of fresh water or kept in the same flowing stream, in other words if the conditions present in the first period are duplicated, the amount removed in this second period will be one half of that which remains or 2.5 grams. The third period will remove 1.25 grams, the fourth 0.75 gram, etc.

This law may be expressed mathematically. Thus the quantity of thiosulphate washed out of the film in a period of t minutes from the start is given by

$$\frac{dM}{dt} = k(A - M),$$

where A is the quantity of thiosulphate originally present, k the elimination constant for the film (50 per cent in the above example).

Then

$$\int \frac{dM}{A - M} = \int k dt$$

and therefore

$$\log \frac{A}{A - M} = kt.$$

Then

$$k = \frac{1}{t} \log \frac{A}{A - M},$$

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[13] Lumière and Seyewetz, *Bull. Soc. franc. Phot.*, 1910. Warwick, *Amer. Phot.*, 1917, p. 317; *Brit. J. Phot.*, 1917, 64, 261. Elsden, *Phot. J.*, 1917, 57, 90; *Brit. J. Phot.*, 1917, 64, 120. Hickman and Spencer, *Phot. J.*, 1922, 62, 225.

which may be written

$$k = \frac{1}{t} \log \left(\frac{\text{initial concentration in film}}{\text{concentration at time } t} \right).$$

The value of k is independent of the initial concentration and may be obtained from

$$k = \frac{1}{t_2 - t_1} \log \left(\frac{\text{Concentration at time } t_1}{\text{Concentration at time } t_2} \right).$$

From which the time required to reach any limiting concentration C_L is given by:

$$t_L = \frac{1}{k} \log \frac{Ct_n}{C_L} + t_n.^{14}$$

So much for mathematical methods which are interesting as they show theoretically to what extent the thiosulphate may be reduced by a given amount of washing. There is some doubt, however, as to their value when applied to practical work. Naturally the above formulas may only be used when the rate of diffusion from the film follows the exponential law and it is by no means established that this is always the case. Hickman found that under certain conditions the rate of elimination followed the exponential law very closely but under other conditions contradictory results were obtained.

The Efficiency of Washing Devices.—The most comprehensive study of the efficiency of various types of washing devices which has yet been made is that by Hickman and Spencer. Owing to the errors in estimating very small amounts of thiosulphate by the usual starch-iodide method and also to the fact that such tests do not necessarily represent the concentration of thiosulphate in the film, since this may be higher than that of the wash water, and also to the fact that the thiosulphate remaining in the film may be localized in spots rather than distributed uniformly throughout the film, it was decided to investigate the matter by using a colored dye which diffuses from gelatine films in the same way as thiosulphate and hence would indicate not only the efficiency of the washing device by the time required for the disappearance of the dye, but would also indicate whether the action was uniform over the whole plate. A dye having the required properties was found in tartrazine, which upon test was found to diffuse from the film in the same manner as thiosulphate but much slower,

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[14] Hickman and Spencer, Ibid.

alterations in the rate of washing therefore affect plates dyed in tartrazine in the same way as those containing thiosulphate, but to a different extent.

Investigation of several types of washing devices by this means showed that all are more or less inefficient. While the water changing properties of the washer are of importance, agitation of the water is equally important, for the time required for the elimination of the dye was not always in proportion to the water changing properties of the device, but on the other hand varied considerably, under conditions otherwise identical, according to the agitation of the wash water. Thus plates placed in an inclined trough in which a constant stream of water was running from the tap washed more rapidly as the slope of the trough was increased. Since the amount of water which flowed over the plates was the same in both cases, it is evident that the velocity of the water over the plate is a factor of considerable importance. Tank washers were found to be of varying efficiency according to the provisions made for the exchange of water, but none were found to equal in efficiency the simple inclined trough.

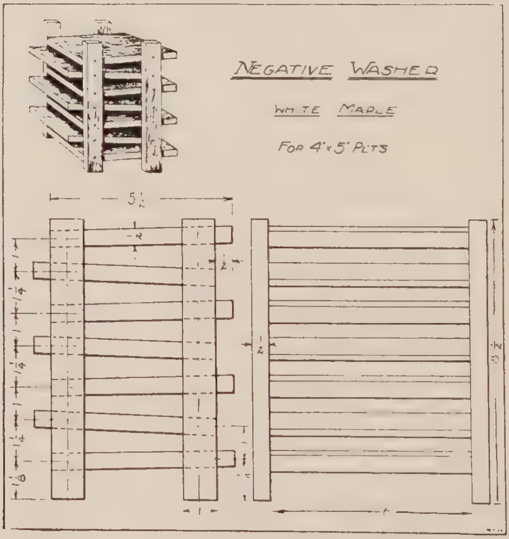

Fig. 154. Windoe's Washing Apparatus

A modification of the trough washer described by Windoes in *American Photography* several years ago is, in the opinion of the writer, one of the most satisfactory devices to be had for the washing of plates. The principle and construction of the apparatus are made clear in Fig. 154. The plates are placed film side up on each of the shelves and the whole rack placed under the tap. The water flows in a thin, fast moving stream over the surface of the plate and then over the edge of the shelf on to the next plate and so on down to the bottom plate. Of course the top plate will be completely washed a little sooner than those beneath it owing to the fact that it receives fresh water directly from the tap while the others receive water partially laden with hypo from the plates above; this is of no serious consequence and the last plate will be washed much more quickly than in the conventional tank washer.

For the washing of roll film in the strip the writer knows of no means more efficient than the Trox film washer supplied by George Murphy Incorporated, 57 East Ninth Street, New York City. This little device (Fig. 155) sends a thin spray of fresh water down both sides of the film which results in quick and effective elimination of hypo.

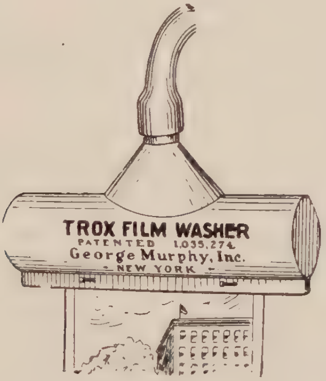

Fig. 155. Trox Washer for Roll Film

In cases where the amount of water available is limited, attention may be drawn to the fact that the greatest efficiency will be obtained by dividing the available supply into as many changes as possible without making each change too small to cover the plates or film. Ten gallons of water applied in ten changes of one gallon each is much more effective as regards removal of hypo than the same quantity in two changes of five gallons each.

The Washing of Prints.—It has always been supposed that under similar conditions prints could be washed free from hypo in the same or even less time than plates owing to the fact that the hypo would be able to diffuse from both sides. This was based upon the assumption that the diffusion of hypo from papers followed the same exponential law as found for plates. Hickman and Spencer, however, have shown that such is not the case.[15] While the larger part of the hypo is removed from the emulsion in a comparatively short time (as much as 90 per cent being removed by two minutes' washing under certain conditions and with certain papers) a certain amount is tenaciously retained by the fibers of the paper support and this is difficult of removal. For this reason much longer times of washing are required for prints than for plates or films. Prints on thin papers should be washed at least thirty minutes in a running stream of water while the thicker double weight papers should receive from one to one and one half hours' washing. Increasing the velocity of the water or the flow of water over the prints does not decrease the time of washing correspondingly, as in the case of plates. Provided the prints are kept separated the removal of the hypo retained by the paper base appears to be largely a matter of time and not of amount of water or the velocity employed.

Unfortunately washing devices for prints are even more unsatisfactory than those supplied for plates. No really efficient and entirely satisfactory apparatus for the washing of batches of prints has yet been devised. The greatest difficulty arises in keeping the prints properly separated in order that the water may have complete access to the surface of each print. To this end it is advisable to avoid overloading of the washer and to separate the prints now and then by hand if necessary.

The additional safety afforded in the case of both prints and negative materials by squeezing after washing so as to remove all surplus water is not often realized. The water adhering to the gelatine film always contains *some* hypo, even if to a very small degree, and the removal of the bulk of this water by squeezing removes much hypo. Furthermore, it prevents the formation of drops which concentrate the small amount of hypo left into centers, in which it may be sufficiently great to cause fading.

Chemical Tests for Hypo.—To determine the thoroughness of the elimination of hypo from a batch of films or prints, any of the chemical tests for the presence of hypo may be applied to the drippings from the surface of a negative, or print, collected for that purpose in a test tube. If to this water a few drops of the following permanganate solution are added, the appearance of a greenish-yellow color is an indication of the presence of hypo:

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[15] *Phot. J.*, 1925, 65, 443.

Potassium carbonate	5 gr.	1 gm.
Potassium permanganate	½ gr.	0.1 gm.
Distilled water to	10 oz.	1000 cc.

The change is rather slow, however, when the quantity of hypo is very small and from a practical standpoint the use of iodine starch in the form advised by Clark and Jelley is preferable.[16]

Two stock solutions are made:

A. Iodide	4 oz.	100 gm.
Potassium iodide	4 oz.	100 gm.
Water to	10 oz.	1000 cc.
B. Sodium azide	4 oz.	100 gm.
Water to	10 oz.	1000 cc.

A starch mixture is also prepared by mixing 90 grains (6 gm.) of soluble starch with cold water and adding this to 7 oz. (200 cc.) of boiling water. On cooling, dilute to 25 ounces (800 cc.) and add 60 minims of Solution A (3.25 cc.) and 235 minims of Solution B (13 cc.) diluting finally to a total of 35 ounces (1000 cc.). This stock solution keeps well and for use is diluted with one hundred parts of water. If a small quantity of this solution is placed in a test tube and the drippings from a negative or print are collected in the tube, the blue color of the solution will be immediately discharged if hypo is present.

Hypo Eliminators.—Many attempts have been made to find a substance which is capable of destroying hypo or converting it to some substance which can be quickly washed out of the gelatine film. Lumière and Seyewetz in 1902 as the result of an investigation of the efficiency of a number of oxidizing agents as hypo eliminators recommended for this purpose ammonium persulphate, potassium percarbonate and sodium peroxide, which in solution immediately hydrolizes into caustic soda and oxygen. This is, I believe, the first indication of caustic alkalis as hypo eliminators.[17]

Gaedicke in 1906 again called attention to the fact that ammonium thiosulphate is more quickly eliminated from gelatine films than the corresponding sodium compound and suggested that the negative, after one minute's washing under the tap, be transferred to a tray containing a 10 per cent solution of ammonium chloride, then washed in four changes of water.[18] The danger in this procedure is the very rapid decomposition of the ammonium hyposulphites formed, this being much more rapid than the sodium compound.[19]

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[16] *Brit. J. Phot.*, 1929, **76**, 714.

[17] *Bull. Soc. franc. Phot.*, 1902, p. 270.

A. Charriou[20] published some notes on the use of sodium bicarbonate but owing to the experimental methods employed his conclusions are unconvincing and there is some question as to the accuracy of the results obtained by him.[21]

A. E. Amor[22] gives details of some investigations on the action of caustic soda at various concentrations and on ammonium persulphate, hydrogen peroxide and potassium permanganate. A 0.2 per cent solution of caustic soda and potassium persulphate were found to be the two most efficient eliminators but neither represents a decided superiority over washing in running water provided that this is properly used. The infinitesimal trace of hypo adsorbed by the gelatine and silver image can be displaced a little more quickly by the use of a mildly alkaline bath, shortening the time of washing by five or ten per cent. There is no saving of time, however, since a minute's longer washing would do as much as an eliminator bath of the same duration. Altogether, then, it appears that there is no advantage whatsoever in the use of the so-called "eliminators" of hypo. Plenty of water properly applied is still the secret of thorough hypo elimination.

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[18] *Phot. Woch.*, Jan. 30, 1906, p. 41.

[19] Lumière and Seyewetz, *Brit. J. Phot.*, 1908, **55**, 417.

[20] *Compt. rend.*, 1923, **117**, 482.

[21] L. P. Clerc, *S. I. P.*, 1923, **3**, 16.

[22] *Brit. J. Phot.*, 1925, **72**, 18.

CHAPTER XV

DEFECTS IN NEGATIVES

Their Cause and Remedy

The Why of Defects.—The troubles of the amateur are due to non-observance of the simple physical and chemical laws upon which the operations of exposure, development and the after processes of fixing and washing are based. Most photographic work is conducted in a haphazard, totally unscientific way. Rule-of-thumb methods, while reasonably certain in the hands of the experienced professional, who works under standardized conditions, are unsuited to the variable conditions under which the average amateur works and, when we add to this the carelessness and want of accuracy shown by the average amateur, it is not surprising that he meets with a great variety of troubles. In dealing with photographic products, we are dealing with highly sensitive and complex chemical products which naturally demand careful treatment, and we must exercise accuracy and care or we are sure to have trouble. The importance of systematic methods of working cannot be too strongly emphasized. Such methods as have been given in preceding chapters are based upon sound scientific facts and, if carried out to the letter, few will be the chances of error and the usable percentage of work will, consequently, be very high. System, accuracy, careful attention to details, cleanliness, these are the things which every student must observe in practice if he would make a success of photography.

Thin Negatives.—A negative is thin either because it has received insufficient exposure or has been underdeveloped.

An *under exposed* negative lacks density because the action of light has not been sufficient to affect the number of silver grains required to produce a deposit of the proper opacity. Careful examination of an under exposed negative will also reveal an absence of detail in the shadows and further examination that the gradation is also false. Owing to the inaccuracy of the eye, this latter may not be particularly noticeable, but it is nevertheless present and is detrimental to the excellence of the finished product. There is no remedy for an under exposed negative. The only thing that can be done is to make another negative, if possible, and give at least double the exposure.

An *underdeveloped* negative is thin because development has been stopped before the reducer has had an opportunity to reduce the number of exposed silver grains required to produce the proper density and contrast. We have learned that contrast increases as development is prolonged, so an under developed negative lacks contrast and should have been developed for a longer time or in a stronger developer. In determining whether thinness is due to under exposure or to under development, the important thing to observe is the shadow detail. If shadow detail is lacking, then under exposure is indicated, while lack of contrast or " snap," with full shadow detail, shows under development. Under exposure cannot be remedied but under development may be corrected by intensification, which will be treated in the following chapter.

Dense Negatives.—Dense negatives may be due either to over exposure or over development. In the first case, the negative is flat, appears fogged and perhaps unsharp, while the shadows possess too much detail. The highlights print gray, the half tones only a shade darker and the shadows also print gray, the proper gradation from light to dark is lacking, and the effect is flat and weak. Such a negative may be somewhat improved by reduction in a subtractive reducer of the Farmer type, as described in the following chapter.

An over developed negative is very contrasty. The highlights, or dense portions, are so opaque that it is impossible to print through them and in attempting to do this, the shadows are considerably over exposed and become too dark. The remedy is to reduce in a superproportional reducer.

Fog on Negatives.—Fog may be defined as a uniform deposit of silver extending over and either partially or wholly obliterating the image. It may be either general or local and due to the accidental admission of light during the operations previous to development, to the use of an unsafe light in development, or from developers contaminated with foreign substances or used at an excessively high temperature or containing an excess of alkali. In fact it may be produced from any number of causes and for this reason its source is quite often difficult to ascertain. It may simplify discussion of the subject if we differentiate between local fog, general fog produced by light and chemical fog.

Local Fog.—Local fog is frequently due to faulty plate holders, the wood having split or the joints become loose in some places so that light is admitted. Examination of the plate holders and a comparison of the location of the fog area by means of a developed negative placed in the holder in the position occupied during exposure will serve to show if this is the trouble.

Fog sometimes results from the use of a plate holder not made for the particular camera on which it is being used. While the majority of modern cameras take what are termed standard holders there are some few cameras made for differently designed holders and when one of these is used with a camera for which it is not designed the fit is imperfect and light leaks in producing local fog.

It sometimes happens, particularly with view cameras, that after long use the reversible back will become worn or warped so that it does not fit tightly to the body of the camera and light is able to reach the plate. The same case occurs sometimes when a new reversing back is purchased to replace an old one.

A frequent cause of local fog with beginners is due to improper insertion of the slide of the plate holder. Beginners have the habit of inserting the slide by the corner but this should never be done as it allows the light to pass through the trap around the edges of the slide and produce fog. The slide should be inserted squarely so that the entire opening is closed at once. It is well as a matter of precaution to keep the camera covered well with the focussing cloth when withdrawing or inserting the slide in order to prevent the accidental admission of light.

Fog may sometimes be produced by chemical emanations from the wood or varnish of the plate holders. This is more likely to occur with new plate holders or when the plates are left in the holders for several weeks. If this is thought to be the source of the trouble, the plate holders should be exposed, with the slides withdrawn, to strong sunshine for several days or the woodwork painted with a solution of potassium permanganate.

Fog is often produced in a similar way with metal plate holders as supplied with many foreign hand cameras. The best remedy is to paint the inside of the holder with a weak solution of bichloride of platinum. Exposure to light and air as formerly advised is also effective in many cases.

General Fog Due to Light.—General fog all over the plate may be due either to light or to chemical fog. If the edges of the plate which are protected by the rabbet are perfectly clear, fog is due to an opening in the bellows or camera front or to the bellows having worn smooth and shiny from constant use so that it reflects light about within the camera. Light leakage by the camera front or bellows may be determined by taking the camera into a dark room and placing a lighted electric bulb in it, using the focussing cloth to make a light-tight entrance for the cable. By inserting the lamp first in one end of the camera and then the other and examining the same from all angles the leaking of light through any minute crevice may be immediately detected. If the bellows has worn smooth and shiny on the inside so that it is suspected of producing fog by reflecting light about in the camera it is best replaced by a new bellows. If any wooden or metal parts of the camera have worn shiny and are suspected of causing trouble in the same way they should receive a coat of dead black paint as supplied by dealers.

If the edge of the plate or film which was protected by the rabbet is also fogged, the plate was either loaded or developed in an unsafe light unless the fog was produced by chemical reactions. A plate is very much more sensitive to light when dry than after it has once been covered by the developing solution and for this reason it is very important that the safelight used for loading plate holders be adapted to the plate and that the operation of loading be conducted as quickly and as far away from the safelight as possible. It is far better, and not at all impossible after some experience, to load plates in perfect darkness and thereby avoid all danger of light fog at this stage.

Extreme precautions should also be taken during development to protect the plate from the rays of the safelight except when absolutely necessary for examination. Once it is seen that the plate has been evenly covered by the developer, there is no need to examine the same for several minutes, or until development is judged to be nearly completed, when the plate may be removed and given a momentary inspection before the light. Prolonged examination of the plate before the safelight is responsible for many fogged negatives as well as stains of various kinds.

When desensitizers are used, greater liberty may be taken with regard to light during development but the safety of the safelight used for loading and for immersing the plates in the desensitizer must be unquestionable, just as when development is conducted under ordinary conditions.

Chemical Fog.—A certain amount of chemical fog is inevitable but with proper working conditions the amount may be reduced to a point where it is of no importance except in sensitometry. The amount of chemical fog is determined by a number of factors: namely, the nature of the emulsion, its age and the conditions under which it has been stored, the nature of the developer, impurities in the developing solution and the time and temperature of development.

Ultra sensitive emulsions are more likely to fog chemically than those of lesser sensitiveness owing to their highly sensitive character and to the small amount of energy required to make the silver halide grain developable. Low speed emulsions of the type represented by positive emulsions and process plates are usually practically free from fog unless developed under unsuitable conditions.

The age of the plate and the conditions under which the plates have been stored play an important part. Sensitive material should never be stored where it is exposed to heat, chemicals, dampness, or in a room where gas is burned.

While the common developing agents differ slightly in their fogging propensities, none produce sufficient fog to be of serious importance in practical work except where improperly used. In the presence of an excess of alkali, or when used in a very concentrated solution, such active agents as metol do tend to develop fog owing to the reduction of unexposed silver halide. The correct proportion of alkali to be used under given conditions can only be determined by experiment.

Sulphite, whether in the form of sodium sulphite, bisulphite or potassium metabisulphite, is added to prevent the oxidation of the developing solution by air, the oxidized solution tending to produce fog. If an excess of sulphite is added a particular kind of fog, known as sulphite fog, is produced. The nature of sulphite fog was carefully investigated by Mees and Piper in 1911[1] and found to be due to the reduction to metallic silver of the silver salt dissolved in the emulsion by the sulphite of the developing solution.[2]

The oxidation of certain developing agents such as metol and hydrochinon exerts a powerful fogging action. The brown oxidized product of pyro, however, has little fogging tendency unless in very strong solution. In general, however, it may be said that the oxidized products of all developing agents tend to produce fog when sufficiently concentrated.

Oxidized samples of the developing agent used in compounding solutions are responsible for fog in many cases. Stale sodium sulphite containing sodium sulphate causes fog indirectly by not preventing the oxidation of the developing solution.

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[1] *Phot. J.*, 1911, **51**, 226; 1912, **52**, 221.

[2] For another form of sulphite fog see *Zeit. wiss. Phot.*, 1913, 289.

Intense fog is produced by such metallic substances as copper, tin, and the metallic sulphites even when present in a very small quantity. Less than .01 per cent of copper sulphate added to a metol-hydrochinon developer will produce strong fog even on positive, low-speed emulsions. The action is probably due to an acceleration of the rate of oxidation.

The activity of the developing solution becomes greater with an increase in temperature and under suitable conditions this may be sufficient to enable it to attack the unexposed silver halide and produce fog. For this reason a temperature above 70° F. (21° C.) is especially conducive to fog.

As the amount of fog grows incessantly with the time of development, it is unwise to attempt to force development in order to secure greater contrast or shadow detail as by so doing chemical fog is developed and this being stronger in the shadows than in the higher densities reduces rather than increases the contrast of the negative.

The amount of chemical fog may be reduced by the addition of a soluble bromide to the developing solution but it is far better to determine if possible the source of the trouble and take appropriate steps to remedy the same. The use of fresh, properly compounded solutions containing the proportions of developing agent, sulphite and alkali advised by the manufacturer of the brand of plates employed, and keeping the developer free from foreign matter and at a normal temperature of 60–65° F. will reduce the danger of chemical fog to the minimum.

Dichroic Fog.—Fog which appears green by reflected light and red by transmitted light is termed *dichroic* (two-colored) fog. It was formerly quite common, but is now comparatively rare due to improvements in the manufacture of ultra sensitive emulsions and to the use of the carbonates of sodium or potassium in place of ammonia as an alkali.

When examined under the microscope the fog is seen to consist of microscopic particles of metallic silver. The size of the particles determines their color by transmitted light, a fog which is red in color consisting of very small particles.

Dichroic fog may be formed either in the developer or the fixing bath. Its formation is aided by the presence of any solvent of silver in the developer or the fixing bath. Frequent sources in development are the presence of such silver solvents as ammonia, or hypo, and prolonged development. Nowadays it most frequently occurs as the result of using an old or exhausted fixing bath containing an excess of dissolved silver and oxidized developer and a deficiency of acid. The presence of sulphur due to the use of too much acid so that the thiosulphate is decomposed and sulphur liberated is also a frequent cause.[3]

Three methods are recommended by Lumière and Seyewetz as being suitable for removal of dichloric fog. They consider the method which follows the most generally useful.[4] Immerse the plate in a solution of potassium permanganate (½ grain to each ounce of water) until the fog is dissolved, then rinse and place in a 5 per cent solution of sodium bisulphite or potassium metabisulphite to remove the brown oxide of manganese which is deposited.

Developer Stains.—While in reality a stain may be considered to be any deposit foreign to the photographic image which absorbs light, in general the word stain is usually associated with something colored. A stain may therefore be considered as a deposit on a negative or positive whose color is foreign to that of the photographic image. This definition thus includes colored spots, irregular colored markings and general stain.

Practically all developing agents have the property of combining readily with oxygen especially in alkaline solution to form colored oxidation products the staining properties of which are very similar to aniline dyes. Furthermore the process of development is in itself an oxidizing process and this results in an additional amount of oxidation which is of course proportional to the amount of silver reduced in the various portions of the image. Consequently the developed image consists of an image of stain superimposed over one of metallic silver. The amount of the stain is greater with some developers than with others and is considerably influenced by the proportion of the sulphite present in the developing solution. Pyro is a developer which is especially prone to give a strong stain image but there is really no excuse for the habitual production of badly stained negatives when pyro is used as the degree of staining is completely under the control of the worker. By increasing the proportion of sulphite to pyro the color may be decreased almost to a neutral black while decreasing the amount of the sulphite will increase the color. Provided the stain is not over intense such staining may not be objectional and may at times be actually an advantage as it increases considerably the printing contrast of the image. Most developing agents form a stain image, though with developers like glycin, the oxidation product of which is readily oxidized by sulphite, the stain image is very feeble and practically negligible.

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[3] For a complete discussion of the causes of dichroic fog reference should be made to a paper by Lumière and Seyewetz, *Bull. Soc. franc. Phot.*, 1903, pp. 501, 529; *Phot. J.*, 1903, 43, 223.

[4] *Bull. Soc. franc. Phot.*, 1903, p. 324; *Phot. J.*, 1903, 43, 226.

Besides the stain image just considered we may have a general yellow, or other colored stain, which is in effect just the same as if the negative had been immersed in a dye solution. When uniform it has no harmful effect other than to increase the time of exposure in printing. It is produced by the use of an old and discolored developing solution, an insufficient amount of sulphite or the use of impure sulphite and in many cases by the use of an old fixing bath which has lost its acid reaction. Since a developer is oxidized far more rapidly in alkaline or neutral solutions than when in an acid state, as the fixing bath becomes neutralized by the alkaline developer carried over on the surface of the negatives, this developer oxidizes more and more readily so that the fixing bath is converted into practically a weak dye solution and stains the negatives immersed therein. It is very important that the fixing bath be kept fresh and acid in order to prevent stain from this source especially when a developer which tends to stain readily is used. The use of a stop bath of a weak acid between development and fixing is also advantageous.

To remove developer stain proceed as follows:

First harden the film by immersion for 2 to 3 minutes in a 5 per cent solution of formaline and wash for 5 minutes to prevent the gelatine from swelling and frilling in the subsequent treatment. Then bleach in the following:

A.	Potassium permanganate	5 gm.	75 gr.
	Water to make	1 liter	32 oz.
B.	Sodium chloride (common salt)	75 gm.	2½ oz.
	Sulphuric acid (C. P.)	15 cc.	½ oz.
	Water to make	1 liter	32 oz.

For use take equal parts. The stock solutions keep excellently but not when mixed and therefore the bleaching bath should be prepared immediately before use.

No particles of undissolved potassium permanganate must be allowed to remain in solution A, otherwise there will be spots and blemishes on the negative.

The bleaching is complete in about three or four minutes after which the brown stain of manganese oxide is removed with a 5 per cent solution of bisulphite. Then rinse and develop in a strong light in a non-staining developer such as metol-hydrochinon.[5]

Local yellow stains on prints or negatives may be removed by superimposing a deep yellow filter over the negative and making a positive either by contact or in the camera and from this making a new negative. A panchromatic plate must of course be used and the yellow filter must be a contrast and not an orthochromatic filter.

Silver Stains.—The use of an old and exhausted fixing bath containing an excess of silver in solution produces what is termed silver stain. A silver stain may also be produced by incomplete fixation of the negative in a fresh bath. In both cases the stain is due to the incomplete removal of the light-sensitive silver halide in the fixing bath. This undissolved silver halide is at first colorless but is gradually changed with time and exposure to a yellow stain. Hence the necessity for thorough fixing.

In the event that it is decided to try one of the methods advised for removal of silver stain it is well to first make the best possible positive from the stained negative using a deep yellow filter on a panchromatic plate as previously described under developer stains, since there are no methods of removing silver stain chemically which are entirely successful. The following method advised by Mr. J. I. Crabtree is probably as good as any: Wash the negative thoroughly to remove all traces of hypo which may be present in the film and bathe the negative in a 1 per cent solution of potassium cyanide. (Cyanide is a deadly poison and must be handled with care.) The cyanide will dissolve any silver thiosulphate present and some silver sulphide but in time it will begin to dissolve the silver image at which stage the negative should be removed and thoroughly washed in order to prevent reduction. Immersion in a weak solution of potassium permanganate followed by washing and immersion in the cyanide solution will often be found of service in dealing with a very old stain.

Miscellaneous Stains.—Stain sometimes occurs when ferricyanide reducer is used. To remove this stain immerse the plate in

Nitric acid	30 min.	6 cc.
Alum	30 gr.	6 gm.
Water to make	10 oz.	1000 cc.

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[5] I am indebted to Mr. J. I. Crabtree for the above formula which is remarkably efficient. *Brit. J. Phot.*, 1921, **68**, 296.

Printing transferred to the gelatine owing to plates having been wrapped in printed matter is almost impossible to remove. Try the following:

Hydrochloric acid	5 drops	5.2 cc.
Water	1 oz.	100 cc.

A yellowish-white opalescence which causes negatives to appear as if made on opal or ground glass is caused by the presence of colloidal sulphur due to the use of an improperly compounded fixing bath containing an excess of acid or to using the fixing bath at a very high temperature. In both cases there is a precipitation of sulphur which fixes itself in the film and produces a sulphur stain. To remove a sulphur stain first harden the film in a 5 per cent solution of formaline, wash well and immerse in a 10 per cent solution of sodium sulphite at a temperature of 100 to 110° F. This is a risky procedure but is the only means of removing such stains.

Blue stains are most often due to iron in some form, although amidol produces a bluish stain which may be removed by dipping the plate in a 10 per cent solution of sodium carbonate. In addition to blue stains, iron salts may produce green or yellowish-brown spots and whenever these appear it is very likely that iron in the water used for mixing solutions, or in the water used for washing, is the source of the trouble. Stains and spots due to the presence of iron are generally removable by means of the bleaching solution advised for the removal of developer stain. Other methods advised are the use of a 5 per cent solution of ammonia, or a 5 per cent solution of oxalic acid.

A blue-green stain apparent after fixing occurs frequently when a chrome alum fixing bath is used at a high temperature. There is no known means of removing such stains. Prevention is the only cure.

Transparent Spots.—Small microscopic spots irregular in shape and sometimes almost microscopic in size are due to dust. Keep the inside of the camera free from dust and clean plate holders now and then with a rag moistened with oil. Allow sufficient time for the oil to evaporate before again using the holders and do not use too much oil in the first place. The merest trace is sufficient. Dust all plates carefully before placing in holders. Use a camel's hair brush and do not brush too briskly, otherwise the glass will be electrified and attract dust thus making matters worse instead of better. The use of a stiff brush will produce friction marks and only a soft camel's hair brush should be used and this but lightly.

Small transparent spots, circular in shape, are due to air in the water used for diluting the developer. Distilled, or at least boiled, water is to be preferred for all solutions but should tap water be used, it is necessary that it be allowed to stand until all the air has escaped. This is particularly necessary when high pressure water mains form the source of supply. Excessive agitation of the developer is another source. A slow, steady, rocking motion is all that is required and is much better than an occasional vigorous rock.

Small, circular, transparent spots with shaded edges are due to air bells adhering to the plate during development and protecting the emulsion from development. The diffuse edge is without doubt due to the slow encroachment of the developing solution. These are very apt to occur in tank development with closed tanks. Some workers find that immersing the plates in water before filling the tank with developer assists in preventing such pinholes, but undoubtedly the surest way is to use only water from which excess air has been expelled by boiling and to avoid carefully any undue agitation.

Spots of irregular shape and about the same size as those formed by air bells are often found distributed along one side of the plate and less rarely over the whole surface. They are caused by a stale developer.

A spot of bare glass which is uncovered by gelatine is one of the few defects caused by faulty manufacture of sensitive materials and is seldom met with when using a reliable brand of plates or film.

Opaque or Semi-Opaque Spots.—The most common cause of small irregularly shaped black or dark spots is the presence of undissolved particles of the developing agent on the plate during development. Care should be taken to thoroughly dissolve every chemical in compounding developing solutions, otherwise a few particles of the developing agent or alkali may be left and these when brought in contact with the sensitive material in development produce dark spots owing to the greater rapidity of development at such spots.

A less common cause of such spots is the presence of iron in solutions or in the water used for washing. In this case, however, the spots are more likely to be colored than black.

Brown or purple spots may be caused by dry particles of developing agents having settled upon the dry plate. Do not mix chemicals in the same room in which plates are developed if possible to use another room. Spots such as these may be removed occasionally by using one of the methods previously advised for developer stains. Touching the spots with nitric acid is sometimes effective but is rather risky. If the worker is familiar with the use of a knife on the film they are best removed in this manner.

Yellow spots, circular in shape, are due to air bells adhering to the plate in the fixing bath. If observed when removing the plate from the fixing bath they can be removed by swabbing the plate with absorbent cotton and re-fixing. If of considerable age there is no means of removal other than those given under silver stain.

Miscellaneous Troubles.—Streaks and blotches, resembling finger marks, brush marks, etc., are caused by old or incorrectly compounded developer. They are most common with hydrochinon or pyro and may be overcome by using a more concentrated solution.

Cloudy or wavy appearance of the negative is due to the use of insufficient developer to cover the plate or by not rocking the tray often enough during development.

A white crystalline deposit on the surface of the dry plate indicates very imperfect washing. Wash the plate again and make a thorough job of it. Immersion in a weak acetic acid bath may assist in removing such deposits.

Frilling or softening of the film occurs only in very hot weather or when there is a wide variation in the temperatures of the successive baths. If it is impossible to keep the developer cool, the plate may be immersed in formaline (10 per cent solution) before development, an acid fixing bath used and care taken to keep the temperature of all the baths on about the same level. Acetone may with advantage replace the alkali in certain developers as it does not tend to soften the gelatine. Amidol which does not require an alkali is also very satisfactory. Frilling and blisters may also be caused by using a fixing bath that is too strong. There is no necessity for using a fixing bath containing more than 30 per cent sodium thiosulphate and at such concentrations there is but little danger of blisters or frilling except under abnormal conditions.

Negatives which are uneven in density due to having dried more rapidly in some places than in others may frequently be improved by bleaching and redevelopment as already described.

CHAPTER XVI

REDUCTION AND INTENSIFICATION

Part I. Reduction

Reduction and the Three Classes of Reducers.—The operation by which some of the metallic silver forming the image is removed so as to secure less opacity is called reduction. All reducing agents are capable of converting the metallic silver into some salt which may be immediately dissolved away. The following table shows the different types of reducers and their characteristics:

Name of Type	Other Names	Characteristics	Examples
Subtractive	Surface Cutting	All densities reduced by equal amounts resulting in greater contrast	Ferricyanide-hypo, Potassium permanganate, Iodine-cyanide, Belitzski's
Proportional	Progressive	All densities reduced in same ratio, contrast unaltered	Nietz & Huse permanganate, persulphate formula
Superproportional	Flattening Persulphate	The percentage reduction is greater in the thick parts than in the thin. Results in *less* contrast	Ammonium persulphate, under normal conditions

The first comprehensive examination of a quantitative nature on the action of various reducers on the tones of a negative was made by Huse and Nietz of the Eastman Research Laboratory in 1916.[1] Sensitometric strips were exposed, developed and reduced under accurately controlled conditions. The strips were measured before and after reduction in a Koenig-Martens photometer, ordinary H. and D. methods being applied to the data. The percentage of the original density removed by reduction from each step was then plotted against the log exposure for that particular density. In this way the curves of Fig. 156 were obtained.

Curve I represents a reducer of the superproportional type, represented by ammonium persulphate; curves II and III represent reducers of the subtractive type, curve II representing one division of this class of which potassium permanganate is typical and curve III another division of this class represented by Farmer's ferricyanide-hypo reducer. It will be observed that this last attacks the lower densities more strongly than does the former. Curve IV represents a formula

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[1] *Brit. J. Phot.*, 1916, 16, 7.

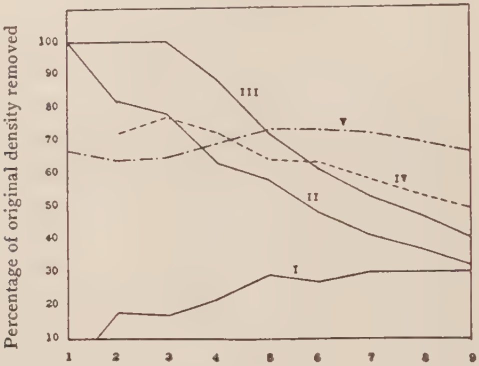
on Seed 23 plate

Fig. 156. Sensitometric Readings of the Action of Different Reducers (Nietz and Huse)

designed by H. C. Deck for proportional reduction and Curve V a modification of Deck's formula worked out by Huse and Neitz.

Farmer's Reducer.—A typical reducer of the subtractive type and one in extensive use is known as "Farmer's" from its originator, Howard Farmer, but it is also called ferricyanide-hypo reducer. It consists of potassium ferricyanide and "hypo." When applied to the plate the silver image is oxidized by the ferricyanide and silver ferrocyanide is formed which is in turn dissolved by the "hypo" according to the equation

$$2K_6Fe_2(CN)_{12} + 4Ag = 3K_4Fe(CN)_6 + Ag_4Fe(CN)_6.$$

Since a mixture of potassium ferricyanide and "hypo" rapidly decomposes, it is necessary to either prepare the reducer immediately before using or keep two separate solutions, one containing potassium ferricyanide and the other hypo. The first may be a ten per cent solution and the latter 20 per cent. Potassium ferricyanide will keep fairly well in water, provided it is protected from light by being kept in a dark cabinet or bottle of dark green glass.

To reduce, sufficient hypo solution (one part hypo to four of water) is taken to cover the negative to be reduced, to which is added a few drops of the potassium ferricyanide stock solution so the color of the solution is pale yellow—not green. Too little ferricyanide is better than too much, since in the latter case reduction proceeds so rapidly that the negative may be reduced further than desired before the action can be stopped. Where extreme reduction is desired the strength of the reducer may be increased. If at the end of five minutes reduction has not proceeded to the desired stage a fresh solution should be applied. Farmer's is a very satisfactory and convenient reducer but should be handled very carefully, since variations in the strength of the solution influence the character of the reduction—a strong solution tends to produce greater contrasts because it affects the shadows to a greater degree.

Belitzski's Reducer.—This reducer is based upon the action of a mixture of the double oxalate of iron and potassium and "hypo" on the silver image. The iron salt yields its oxygen to the silver which forms silver oxide in a nascent condition which is at once dissolved by the "hypo." The reducer keeps well in a dark place and may be used over and over until exhausted. In its action on the tones of the negative it resembles Farmer's very closely. The following is the formula:

Potassium ferric oxalate	148 gr.	10 gm.
Sodium sulphite	59 gr.	4 gm.
Water to make	7 oz.	200 cc.

After completely dissolved add:

Oxalic acid	44.5 gr.	3 gm.

and shake until the solution turns green. Then pour off the clear liquid and add:

"Hypo"	1¾ oz.	50 gm.

Instead of the potassium ferric oxalate the following may be used:

Ferric chloride (crystal)	96 gr.	6.5 gm.
Potassium oxalate	186 gr.	12.5 gm.

Mercury and Cyanide Reducer (Eder's).—The following reducer is similar to Farmer's, but reduces more slowly, is non-staining and intensely poisonous:

Potassium cyanide	24 gr.	5 gm.
Potassium iodide	12 gr.	2.5 gm.
Mercuric chloride	12 gr.	2.5 gm.
Water to make	10 oz.	1000 cc.

Dissolve the mercury, then the iodide and lastly the cyanide which will dissolve the red precipitate formed. On account of its intensely poisonous nature this reducer should be carefully handled and labeled poison.

Iodine-Cyanide Reducer.—This is rather more energetic in its action on the shadows than Farmer's and tends to clean out the lower densities to a greater degree without seriously affecting the higher densities. It is exceedingly poisonous and should be handled with care. It is non-staining and when used weak is a very useful reducer for over-developed bromide prints.

Iodine (10 per cent sol. in potassium iodide sol.)	30 min.	6 cc.
Potassium cyanide (10 per cent sol. in water)	5 min.	1 cc.
Water to make	1 oz.	100 cc.

Since iodine will not dissolve in water, but is readily soluble in potassium iodide, it is necessary to add about 150 grains of potassium iodide to just enough water to dissolve it, then add 45 grains of iodine and make up the solution to a total volume of one fluid ounce.

Permanganate Reducers.—The introduction of permanganates as reducing agents is due to Professor Namias. The permanganates are strong oxidizing agents and if a solution of potassium permanganate containing a small amount of sulphuric acid is applied to a negative the silver is oxidized, forming silver sulphate, which is sufficiently soluble in water to be dissolved. The reaction is as follows (Namias):

$$5Ag_2 + 2KMnO_4 + 8H_2SO_4 = 5Ag_2SO_4 + K_2SO_4 + 2MnSO_4 + 8H_2O.$$

Permanganate is similar in its action on the tones to Farmer's and the other reducers which we have examined, but differs from them in being more nearly proportional in its action and not having quite the same "cutting" effect on the lower densities. The difference in the two classes of reducers may be seen from the examination of Fig. 156, where curve II and curve III show the percentage reduction of the different densities for permanganate and Farmer's respectively.

I.	Potassium permanganate	24 gr.	50 gm.
	Water to make	1 oz.	1000 cc.
II.	Sulphuric acid C.P.	24 min.	50 cc.
	Water to make	1 oz.	1000 cc.

For use take 1 part of *A*, 2 parts of *B*, and 64 parts of water. When sufficiently reduced immerse in a plain hypo solution, fresh acid fixing bath, or 5 per cent solution of sodium bisulphite to remove the brown stain, after which wash well.

Proportional Reducers.—Reducers which act on all parts of the negative in proportion to the amount of silver present are variously known as *proportional, true scale,* and *progressive*, from which the first has been generally accepted of late as the most rational title. While under certain conditions ammonium persulphate may form a proportional reducer its action is uncertain and not to be depended upon but by the proper combination of potassium permanganate, which is a subtractive reducer, with the ammonium persulphate which is of the superproportional type (exactly opposite to the subtractive), a proportional reducer is obtained. The following formula is the one worked out by Huse and Nietz.[2]

SOLUTION *A*

Potassium permanganate..................	4.1	gr.	0.25	gm.
10 per cent sulphuric acid..................	262	min.	15	cc.
Water pure to make........................	35	oz.	1000	cc.

SOLUTION *B*

Ammonium persulphate....................	420	gr.	25	gm.
Water pure to make........................	35	oz.	1000	cc.

For use take one part of *A* to three of *B*. Do not mix until ready for use. The time of reduction is from one to three minutes and should be followed by a one per cent solution of potassium metabisulphite.

Application of Proportional Reducers.—In practice the chief purpose for which a proportional reducer is used is to reduce over dense negatives which are due to over development. Since over development increases the silver deposits proportionately the effect of reduction in a truly proportionate reducer is to lower the gamma or in effect is equal to developing for a shorter length of time.

In Fig. 157 curve I shows the characteristic curve of a plate developed to a certain gamma. Curve II represents a gamma of unity (1). Now, if the negative represented by curve I is reduced in a proportional reducer the result will be a negative possessing the gamma of curve II. A proportional reducer is therefore the only type which alters density without affecting gradation. It is thus the only reducer which may be employed without falsifying to a certain extent the original gradation of the negative.

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[2] Proportional reducers. Communication 39, Research Laboratory of Eastman Kodak Co. *British Journal of Photography,* Oct. 27, 1916; *Australasian Photo-Review,* Dec. 1916.

Superproportional Reducers.—Superproportional reducers are necessary when it is desired to reduce the contrast of a negative in order to make it suitable for a particular printing medium. There is only one reducer having a definite superproportional action and that is ammonium persulphate. This must be used in an acid solution and is rather erratic in action, sometimes acting properly and at other times not. Much of its irregularity is due to the presence of small amounts of other substances, hence in purchasing one should secure only the C.P. salt and this should be kept in airtight containers as it decomposes in contact with air.

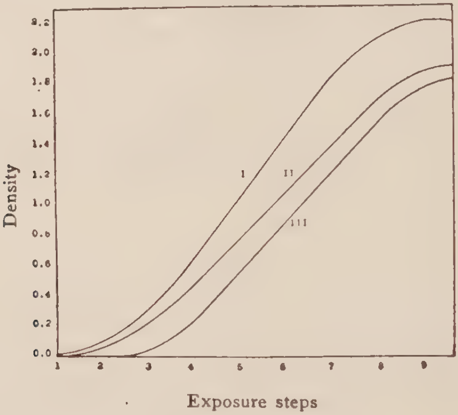

Fig. 157. Action of a Proportional Reducer on the Plate Curve (Nietz and Huse)

Theories of Superproportional Action.—Owing to its peculiar property of attacking the higher densities before the lower and to its erratic behavior, the chemical reaction of the persulphates with the silver image has been the subject of much speculation, but research has not yet been able to explain satisfactorily the reason for its unique property of superproportional action.

A. and L. Lumière, to whom the introduction of persulphate as a reducer is due, developed the following theory of its reaction:[3] The action is regarded as proceeding from the back of the negative to the surface in exactly the reverse method as all other operations progress, thus the lower densities which lie nearer to the surface are the last to be attacked.[4] Helain [5] and Lauder,[6] however, proved that reduction does not take place from the back of the film by exposing plates through the glass and secured the same result, while microscopical investigation by Pigg [7] and by Scheffer [8] shows that the action is uniform on all of the grains of the film and not from the back to front as stated in the Lumière theory.

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[3] *Bull. Soc. franc. Phot.*, 1898, p. 395; Ibid., 1899, p. 226; Ibid., 1899, p. 399.

In 1906 Lüppo-Cramer advanced what is known as the *dispersoid theory.*[9] In this the behavior of persulphate is supposed to be due to the fact that the silver deposit is not metallic silver, as commonly supposed, but a mixture of silver and silver bromide, there being more of the latter in the lower densities. The superproportional action is explained by saying that metallic silver is more soluble in persulphate than silver bromide—a known fact. The action of certain substances which are solvents of silver bromide and render the action proportional is explained by saying that the solvent removes the halide so that it can be more readily attacked by the persulphate.

The *catalytic theory* was developed by Schuller [10] and Stenger and Heller carried on a long series of experiments to prove it.[11] This theory declares that the cause of the superproportional action of persulphate is due to the catalytic effect of the silver ions formed during the reaction of the silver and the persulphate. Since the concentration of these ions increases more rapidly in the higher densities than in the lower the action is greater on the former. Further research will be required, however, to definitely explain the theory of persulphate reduction.

The Practice of Persulphate Reduction.—While reduction with persulphate cannot be said to be an absolutely safe and certain process even with the best of care, yet by the proper observance of several important points serious irregularities in its action will be rare. Only the purest persulphate should be used. Much of the commercial persulphate contains traces of iron and as Sheppard has pointed out this has a catalytic action.[12] The amount of iron necessary to affect its action is on the order of 1 part in 1,000,000 and the limit of tolerance permissible is about 2 parts to 1000 of solid persulphate. A small amount of iron is not a disadvantage but it is essential that the limits are not overstepped and also that the chemical be uniform, or the varying iron content of different samples of persulphate will lead to error. The presence of soluble chlorides, bromides, sulphates, and nitrates in the water used for solution is also a source of trouble and many of the difficulties would disappear if the precaution of using distilled water was adopted. Since the characteristic action of persulphate is vitally affected by the concentration of acid present, a certain amount of sulphuric acid is generally added. With distilled water the required acidity is secured by the addition of about one drop C.P. sulphuric acid to each ounce of solution when freshly mixed. Stock solutions of persulphate are not advisable.

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[4] *Resume Travaux Scientifiques,* pp. 215, 216, 218; *Brit. J. Phot.,* 1898 (45), p. 473.

[5] Theory of Persulphate Reduction, Helain, *Bull. Soc. franc. Phot.,* 1898, 15, 226.

[6] Persulphate of Ammonia, H. S. Lauder, *Brit. J. Phot.,* 1899, 46, 725.

[7] "Action of Ammonium Persulphate on the Photographic Image," J. I. Pigg, *Brit. J. Phot.,* 1903, p. 706.

[8] "Microscopical Researches on the Effect of Persulphate and Ferricyanide Reducers," Scheffer, *Brit. J. Phot.,* 1906, 53, 964.

[9] "Absorption Complexes in the Silver Grain as the Cause of the Persulphate Effect," *Phot. Korr.,* 1908, 45, 159.

[10] "The Theory and Practice of Reduction," A. Schuller, *Phot. Rund.,* 1910, 24, 113.

[11] *Z. f. Reproductions technik,* 1910, 12, 162, 178 and 1911, 13, 5, 20, 34, 50, 70, 84, 100; *Zeit. wiss. Phot.,* 1911, 9, 73, 389.

The plate should be placed in the following solution which should be made up just before use and distilled water only should be used:

Ammonium persulphate	4 gr.	8.3 gm.
Sulphuric acid C.P.	1 min.	2 cc.
Water to make	1 oz.	1000 cc.

The action should be watched very carefully for it becomes more rapid with time and the negative may be reduced further than desired before the action can be stopped. Therefore it is better to remove the negative from the solution just before the reduction has reached the desired stage, preferably using a plate lifter to avoid contamination with the fingers, and place in a five per cent solution of sodium sulphite. While refixing is not necessary it is to be advised, since it leaves the film amenable to further treatment.

PART II. INTENSIFICATION

The function of intensifiers is to increase the density and contrast of a negative so as to obtain better printing quality. Intensification may be necessary for several reasons. The negative may be simply under developed due to an error in the composition of the developer, or the time, or temperature of the same and in such cases the intensifier continues the action of the developer, building the negative up to a higher degree of contrast. Owing to over exposure, or lack of contrast in the subject, the negative may lack the necessary contrast and intensification may be desirable to supply this deficiency.

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[12] *Brit. J. Phot.*, 1918, 65, 314. *Phot. J. America*, 1918, 55, 299.

Intensification may be effected in several ways.

The first and most common method consists in altering the metallic silver grains by treatment with substances which will unite with silver to produce greater opacity.

The second method consists in altering the color of the deposit so that it is less actinic and offers greater resistance to the passage of chemically active light than the original deposit.

The third method is similar to that formerly necessary in the wet process for building up sufficient density and consists in adding a new film of silver to the old, the increased amount of silver increasing the density.

Intensification with Mercury.—After thorough fixing and washing, bleach the negative in:

Mercuric chloride	476 gr.	62 gm.
Hot water	16 oz.	1000 cc.
After cooling add hydrochloric acid	30 min.	4 cc.

When the negative is completely bleached through to the back of the plate remove and wash well in running water; if possible for at least twenty minutes or by giving ten five-minute soakings if washed in a tray. It is then blackened in one of the following:

A. Sodium sulphite 10 per cent solution		
B. An ordinary developer as Amidol, Hydrochinon, Ortol, Glycin, Metol-Hydrochinon, etc.		
C. Sodium sulphantimoniate (Schlippe's salt)	192 gr.	20 gm.
Water	20 oz.	1000 cc.
D. Ammonia (0.880)	20 min.	1.25 cc.
Water	1 oz.	30 cc.
E. The following ferrous oxalate developer:		
A. Potass. oxalate (neutral)	5 oz.	288 gm.
Hot water	20 oz.	1000 cc.
When cool pour off clear liquid for use.		
B. Sulphate of iron	5 oz.	288 gm.
Sulphuric acid C.P	30 min.	3.12 cc.
Water (warm)	20 oz.	1000 cc.

For use take one part of *B* to three of *A*. Pour *B* into *A* and not *vice versa.*

The chemical reaction which takes place when the silver image is bleached in mercuric chloride is represented by the following equation:

$$2HgCl_2 + 2Ag \rightarrow Hg_2Cl_2 + 2AgCl.$$

The resulting chlorides of mercury and silver are transparent and blackening is necessary to secure printing density. With sodium sulphite the reaction is as follows:

$$Hg_2Cl_2 + Na_2SO_3 + H_2O \rightarrow 2Hg + Na_2SO_4 + 2HCl.$$

Blackening in an alkaline developer reduces the deposit to a silver mercury compound whose composition is not definitely known and which probably varies with the developer.

On blackening with ammonia the probable reaction is as follows:

$$Hg_2Cl_2 + 2NH_3 \rightarrow NH_2Hg_2Cl + NH_4Cl.$$

When an image bleached with mercuric chloride is acted on by ferrous oxalate, the image that remains consists of an amalgam of silver AgHg. If the process be repeated each atom takes up another atom of mercury and we get $AgHg_3$ and consequently greater intensification. The reaction would therefore be as follows:

$$Hg_2Cl_2 + 2AgCl + 4FeC_2O_4 + 2K_2C_2O_4 \\ = 2Ag + 2Hg + 2Fe_2(C_2O_4)_3 + 4KCl.$$[13]

Of the several methods of blackening the last is without doubt the most satisfactory. It gives proportionate intensification, a black deposit which is permanent, and may be repeated to gain any desired degree of intensification. Sodium sulphite reduces the lower densities, producing what workers call a clean result, which however is secured at the expense of proportional action and purity of gradation. There is question concerning its permanency. The objection to the use of developers containing sulphite is that already stated as an objection to the use of sulphite alone but there is a further objection to the use of the alkali which can by itself effect a partial conversion of the silver mercurous chloride into the carbonates or oxides. This possibility of two distinct reactions at one and the same time is an important disadvantage which tends to render the action unproportionate and also impermanent. Sodium sulphantimoniate gives approximate proportional intensification and with the exception of ferrous oxalate is the most satisfactory of the lot. With ammonia the blackening is not uniform and the reducing action in the shadows is very marked, the original gradation being altered to a considerable degree. The degree of intensification and action of the various blackeners on the tones of the subject will be treated at the end of the chapter under the Sensitometry of Intensification.

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[13] Chapman Jones, *J. S. C. I.*, 1893 vol. XII, p. 983.

Monckhoven's Intensifier.—The negative is bleached in mercuric bromide as above and blackened in the following solution of potassium cyanide and silver:

Pure potassium cyanide	10 gr.	23 gm.
Nitrate of silver	10 gr.	23 gm.
Water	1 oz.	1000 cc.

The silver and cyanide are dissolved in separate lots of water, and the former solution added to the latter until a permanent precipitate is formed. Then allow the solution to stand fifteen minutes and filter after which it may be used. If the intensification is carried too far the plate may be reduced in "hypo." The reaction according to Valenta is as follows:

$$Hg_2Cl_2 + 2AgK(CN)_2 \rightarrow 2Ag + 2Hg(CN)_2 + 2KCl.$$

Mercuric Iodide Intensifier.—Traces of hypo remaining in the film cause stains and spots with any of the above intensifiers and it is necessary that the greatest care be taken to thoroughly wash negatives before intensifying. It is a peculiar characteristic of mercuric iodide, and often a very valuable one, that its action is not affected by any traces of hypo which may remain in the film and the negative may be removed from the fixing bath, washed for a few minutes in water, and intensified at once.

A.	Mercuric chloride	175 gr.	40 gm.
	Water	10 oz.	1000 cc.
B.	Potassium iodide	1 oz.	100 gm.
	Water	10 oz.	1000 cc.

Add the larger part of the iodide to the mercury, stirring well. Then add the remainder of the iodide in small quantities until the solution clears. The solution changes the negative to a brown color which further changes to orange upon washing in water. Redevelopment in a non-staining developer such as amidol or metol-hydrochinon will render the negative less liable to yellow in time. The chemistry of the reaction is as follows:[14]

$$2HgI_2 + 2Ag = Hg_2I_2 + 2AgI,$$
$$Hg_2I_2 + 2(Na_2SO_3) = Hg + HgI_2 \cdot (Na_2SO_3)_2.$$

Silver Intensifiers.—The following formula and method for silver intensification is that of J. B. B. Wellington and is the revised formula published in 1911.

The film should first be hardened in the following bath:

Formaline	1 part
Water	10 parts

In this bath the negative should be allowed to remain for five minutes, after which it should be rinsed for a few minutes and then placed for *exactly one minute* in the following bath:

Potassium ferricyanide	20 gr.	2.3 gm.
Potassium bromide	20 gr.	2.3 gm.
Water to make	20 oz.	1 liter

This bath, which should never be omitted, has the effect of preventing stains during the process of intensification. Too long an immersion in this bath causes the image to bleach, which should be avoided if it is desired to retain the original gradation. In the time prescribed there is no apparent action, but the clearing agent has done its work. The negative should now be rinsed for a few minutes and intensified in the following:

Stock Solutions

A. Silver nitrate	800 gr.	83.4 gm.
Distilled water to make	20 oz.	1 liter
B. Ammonium sulphocyanide	1400 gr.	146 gm.
Hypo	1400 gr.	146 gm.
Water to make	20 oz.	1 liter

(Both solutions keep well.)

For use take an ounce of *A* to one half ounce of *B*, stirring vigorously all the while the two are mixed. If stirring is omitted the solution is apt to be turbid, whereas it should be clear. To this is added 1 dram of a ten per cent solution of pyro solution, preserved with sulphite of soda, and two drams of 10 per cent solution of ammonia.

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[14] Seyewetz, *Le Negatif en Photographie.*

Place negative in absolutely clean tray and pour solution over it. The silver begins to deposit within a minute or so and when sufficiently intensified the plate should be removed, placed in an acid fixing bath for a short while, and then well washed. Silver intensification is really physical development, silver being deposited upon the original deposit. The action is proportional and the results permanent and a negative intensified with silver may be reduced in any manner.

Intensification with Chromium.—This process is largely due to C. Welborne Piper and D. J. Carnegie.[15] The negative is bleached in a solution of potassium bichromate and hydrochloric acid and the bleached negative blackened in ordinary developer. The bleached image contains a chromium compound the precise formula of which is unknown but is thought to be CrO_2. When this is treated with a developer it is reduced and part of the chromium is left in the image in combination with the metallic silver. While perhaps not absolutely proportional in its action and thus to a certain extent falsifying gradation, the same is very slight, and as the process is easily worked and may be repeated over and over so that any degree of intensification ordinarily desirable may be had, the chromium intensifier is of great practical value. The degree of intensification is controlled to a certain extent by the amount of acid present and it is possible to vary the degree of intensification by altering the amount of acid, the more acid used the less the intensification secured, but on the whole it is more desirable to use one of the three formulas given and if the result is not what is desired after the first application repeat the process. The intensifier may be kept in the following stock solution from which either of the three bleaching baths may be compounded according to the degree of intensification desired:

A.	Potassium bichromate	1 oz.	50 gm.
	Water to make	20 oz.	1000 cc.
B.	Hydrochloric acid C.P.	1 fl. oz.	100 cc.
	Water to make	10 oz.	1000 cc.

Baths ready for use.

	A	*B*	*C*	Degree of intensification
A. Solution	4 oz.	8 oz.	8 oz.	*A*—Maximum
B. Solution	3 dr.	2 oz.	8 oz.	*B*—Medium
Water	16 oz.	10 oz.	4 oz.	*C*—Minimum

Bleach in *A*, *B*, or *C*, wash until yellow stain is removed and then redevelop in a non-staining developer. Amidol is to be preferred, especially if by any chance it is likely that the process need be repeated, as the change from acid to alkali is particularly hard on gelatine and by the use of amidol this trouble is minimized, since amidol does not require an alkali and any tendency of the gelatine to soften and frill is always increased in the presence of an alkali.

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[15] *Amat. Phot.*, 1904, pp. 336 and 397; 1905, pp. 453 and 473.

Intensification with Uranium.—If the silver image is treated with a ferricyanide it is reduced to a ferrocyanide, the probable reaction in the case of uranium ferricyanide being:

$$8Ag + 4(UO_2)_3[Fe(CN_6)]_2 \rightarrow 2Ag_4Fe(CN)_6 + 3(UO_2)_4[Fe(CN_6)]_2.$$

The silver image is therefore converted into a mixture of silver ferrocyanide and uranyl ferrocyanide, the dark-brown or reddish color of which being non-actinic considerably increases the density and contrast of the negative.

Uranium is a great builder of detail and contrast and is perhaps the most suitable intensifier for getting the most out of an under exposed negative—the red deposit being able to build up to printing density all the detail which the exposure has been able to impress on the sensitive material.

The following is a suitable formula:

A.	Uranium nitrate	120 gr.	25 gm.
	Water to make	10 oz.	1000 cc.
B.	Potassium ferricyanide	120 gr.	25 gm.
	Water to make	10 oz.	1000 cc.

For use take: *A*—10 parts; *B*—10 parts; acetic acid—2.5 parts.

The negative must be perfectly free from hypo or stains will result which cannot be easily removed. When intensification is judged to be complete the negative should be removed and washed well in pure water. Hard or alkaline water cannot be used for this purpose for, as pointed out by Sedlaczek,[16] the uranyl ferrocyanide is soluble in alkalis. Should the yellow stain remain after several changes of water its removal may be effected by means of a 10 per cent solution of ammonium sulphocyanide or with

Potassium citrate	5 gm.	38 gr.
Sodium sulphate	25 gm.	192 gr.
Water to make	1000 cc.	16 oz.

If for any reason it should be desirable to remove the intensification altogether this may be accomplished by immersing the negative in a weak solution of ammonia or of sodium carbonate. If the negative is to be again intensified this bath should be followed by a weak bath of acetic acid to neutralize any traces of alkali which might remain in the film.

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[16] *Phot. Ind.*, 1924, p. 234.

Intensification with Lead.—Extreme intensification is secured with lead. Practically the only case in which such extreme contrast is required in ordinary practice is with line subjects from poor originals. The general outline of the chemical reaction is the same as with uranium:

$$2K_6Fe_2(CN)_{12} + 4Ag + 6Pb(NO_3)_2 = Ag_4Fe(CN)_6 + 3Pb_2Fe(CN)_6 + 12KNO_3.$$

The following formula is recommended:

Lead nitrate	400 gr.	41.6 gm.
Potassium ferricyanide	600 gr.	62 gm.
Acetic acid	3 dr.	20 cc.
Water to make	20 oz.	1000 cc.

The stock solution will keep well in the dark.

Bleach the negative in the above and then wash *carefully* in 10 per cent nitric acid—the acid makes the film tender—then in water and then darken in

Sodium sulphide	1 oz.	50 gm.
Water to make	20 oz.	1000 cc.

Intensification with Copper.—The copper intensifier is also only suited to line subjects. The reaction is as follows:

$$CuSO_4 + 2KBr \rightarrow CuBr_2 + K_2SO_4,$$

$$CuBr_2 + Ag \rightarrow CuBr + AgBr.$$

Applying $AgNO_3$,

$$CuBr + 2AgNO_3 \rightarrow Cu(NO_3)_2 + Ag_2Br.$$

The following is a reliable formula:

A. Copper sulphate	100 gr.	208 gm.
Water to make	1 oz.	1000 cc.
B. Potassium bromide	100 gr.	208 gm.
Water to make	1 oz.	1000 cc.

A and *B* are both dissolved in hot water. For use they are mixed and the negative bleached therein after which it is washed for a minute or two and blackened in

Silver nitrate	45 gr.	100 gm.
Water (distilled)	1 oz.	1000 cc.

If too dense the negative may be reduced by the application of a weak solution of hypo (10 grains to the ounce) or potassium cyanide 2 grains to the ounce.

Intensification by Sulphiding.—A very convenient method of securing a limited amount of intensification consists in ordinary sulphide toning of the image. The negative is first bleached in a bath of potassium ferricyanide and potassium bromide, then washed well and finally darkened in sodium sulphide. The metallic silver is thus changed to silver sulphide, the brown color of which is less actinic than the original black. Thus while the negative may actually appear less dense after sulphiding, its printing density has been increased by the process. The operation differs in no way from the toning of gaslight and bromide prints by the indirect, or redevelopment process. The image is permanent.

The Sensitometry of Intensification.—Until quite recently no quantitative measurements of the character and degree of intensification secured with different agents had been made. This matter was first investigated by H. W. Bennett in 1903, by L. P. Clerc in 1912,[17] and more fully by Nietz and Huse.[18]

It is not our business here to go into the experimental methods, or consideration in full of the factors involved, for which the original paper should be consulted, but to note more particularly the character of the intensification secured by representative intensifiers and their relative efficiency.

In the first place it will be necessary for us to notice the difference between visual and photographic intensification, as the two are not the same and we may have one without the other. If the deposit of the original negative is neutral and the intensified deposit also neutral, then any increase in visual density will be a direct measure of the photographic effect. In most cases, however, these conditions are not fulfilled. Some intensifiers depend entirely upon the change of the silver to some material having "a more non-actinic color," as for instance uranium and the sulphide method.

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[17] Bennett, *Phot. J.*, 1903, **43**, 74. Clerc, *Brit. J. Phot.*, 1912, **59**, 215.

[18] Communication No. 58 from the Research Laboratory, Eastman Kodak Company, *The Photographic Journal*, 1918, **58**, 81; *Journ. Frank. Inst.*, March 1918.

The authors distinguish between three general classes of intensifiers:

1. Those giving both visual and photographic intensification, as uranium. A second class of the same giving neutral deposits, as mercuric bromide with amidol and chromium followed by amidol provided the deposit of the negative is neutral. The most generally useful class of intensifiers.
2. Visual reduction but photographic intensification. Example. Redevelopment with sodium sulphide where the visual density is less, but the non-actinic color gives photographic intensification.
3. Visual intensification with photographic reduction obtains only when intensifiers having a bleaching effect are used on negatives of high color. Example. Chromium-amidol on a badly stained pyro negative. A special case only.

In Fig. 158 the percentage increase in density is plotted as the

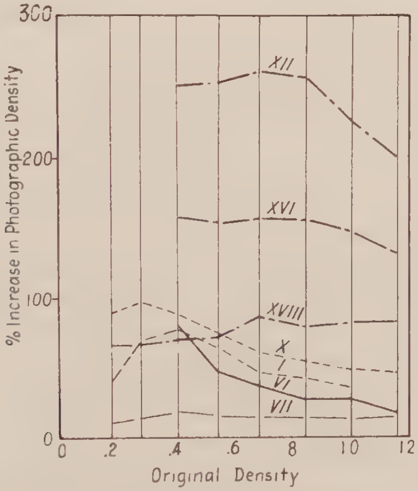

FIG. 158. Sensitometry of Photographic Intensification. (Nietz and Huse) I. Mercuric chloride + ammonia. VI. Chromium + amidol. VII. Mercuric bromide + amidol. X. Mercuric iodide + paramidophenol. XII. Uranium. XVI. Mercuric iodide + Schlippe's Salt. XVIII. Cupric chloride + sodium stannite.

ordinates against the original densities as abscissae. A line parallel with the base would thus indicate proportional intensification. No intensifier reaches absolute perfection in this respect although several approach it very closely.

By plotting the densities of the intensified and original plates against log E in the usual manner employed in sensitometry we get two characteristic curves the difference of whose gammas is a measure of the increase in contrast.

$$\text{Thus } \frac{\text{photographic gamma of intensified plate } y\ ip}{\text{photographic gamma of original plate } \quad y\ op}.$$

gives the degree of intensification. The data for a few representative intensifiers is given in the following table taken from the paper of Huse and Nietz:

Intensifier	Blackener	$\frac{y\ ip}{y\ op}$
Mercuric chloride	ammonia	1.15
Potassium bichromate and HCl	amidol	1.45
Mercuric bromide	amidol	1.15
Potassium ferricyanide and potassium bromide	sodium sulphide	1.33
Cupric chloride	sodium stannite	1.93
Permanganate and HCl	sodium stannite	2.05
Mercuric iodide	Schlippe's salt	2.50

The careful study of this and the preceding table will give the student much valuable information regarding the characteristics of the different intensifiers and their suitability for employment in particular cases.

Local Reduction and Intensification.—Local reduction or intensification is of great assistance at times in bringing out certain details in the shadows or in reducing the density of an over-dense highlight. If the negative to be reduced or intensified has been allowed to dry it should be first soaked for fifteen to twenty minutes in water, while if the negative has been handled it may be well to add to the water a small amount of sodium carbonate to remove any grease present on the film.

It must be remembered that many intensifiers and some reducers (the latter, however, to a minor extent) alter not only the density but also the color of the deposit and this makes it hard to judge accurately the actual amount of reduction or intensification secured. Preference should therefore be given to intensifiers which do not produce a colored image such as chromium or mercury and ferrous oxalate. For reduction, the iodine-cyanide reducer is well adapted but potassium permanganate or Farmer's ferricyanide-hypo reducer may be used.

The negative to be reduced is placed in a horizontal position on a sheet of glass where it will be well illuminated by transmitted light. A convenient reducing bench described by a writer in the *British Journal of Photography* is illustrated in Fig. 159. The solution should then be applied to the desired portions with a soft brush or with a wad of absorbent cotton. Use only a weak solution, otherwise the action may be so rapid as to get beyond control while should any of the strong solution be accidentally carried over on undesired areas, it will be impossible to prevent them from being reduced.

Local intensification may be carried out very simply by the use of colored dyes. These may be applied in a very dilute state to the desired portion and allowed to dry. If too strong the negative may be washed in water to weaken the dye. Suitable dyes for this purpose are erythrosine and the Agfa preparation known as Coccine Nouvelle.

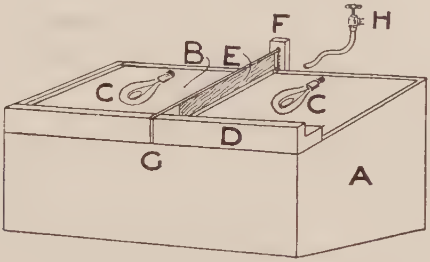

Fig. 159. Bench for Local Reduction. (*British Journal of Photography*)

Namias has recommended that the negative be immersed in a 1/1000 solution of potassium permanganate for a few moments and the yellow stain removed from the portions which it is desired to darken by painting over such portions with a solution of bisulphite of soda.

Some workers find it advantageous to apply to the parts of the negative not to be acted upon by the reducing or intensifying solutions a water-resisting mixture which protects such portions from the action of the solution. The negative can then be immersed bodily in the solution. A varnish suitable for this purpose may be made by adding to benzol or chloroform a very small quantity of masticated rubber or pure white wax (not paraffine wax).

General Reference Works

Bennett—Intensification and Reduction.

CHAPTER XVII

PRINTING PROCESSES WITH SILVER SALTS

I. Printing on Bromide and Gaslight Paper

Characteristics of Printing Papers.—It is the primary object of the photographer to reproduce in the *print* the gradations of light and shade observed in the subject photographed. The negative is an intermediate step; perfect reproduction of the brightnesses of the subject on the negative is of no importance unless the printing process is capable of producing from this negative a print which corresponds to the visual impression of the subject photographed. Accurate reproduction of the gradations of the subject involve, therefore, (1) the production of a negative in which the opacities are inversely proportional to those portions of the subject which they represent, and (2) the production from this negative of a print in which the light reflected from the various parts of the image reproduce the visual impression of the subject photographed. The possibility of accurately reproducing the tones of any subject by photography depends, therefore, not only on the accuracy with which we are able to translate subject brightnesses into opacity in the production of the negative, but also on the extent to which we are able to make from this negative a positive print in which these opacities are correctly rendered as shades of black reflecting amounts of light proportionate to the corresponding portions of the subject.

There is no difficulty in securing correct reproduction in the negative, for, as shown by Hurter and Driffield, this is possible if the straight-line portion of the curve of the sensitive material is used, and with negative materials the straight-line portion is sufficiently long to take care of the range of light intensities in all ordinary subjects.

Printing papers show the same type of curve as do negative materials and in both cases the length of the straight-line portion determines the range of light intensities over which correct reproduction is secured. Now assuming that the gradations of light and shade in the original subject are correctly represented by the opacities of the negative, perfect reproduction of the original subject will be obtained if we use the straight line portion of the curve of the printing paper in making the print.

The length of the straight-line portion of the curve of a printing paper, however, is much shorter than that of negative materials. The greatest range of light intensities possible with a printing paper is the ratio between the amount of light reflected from the white paper and that reflected from the deepest black which the paper is capable of producing. The maximum black which a paper is capable of producing varies with the emulsion and with the surface of the paper. With a matt paper the difference in the amount of light reflected from the white paper and the maximum black of the paper may be in the ratio of 1 : 15; with glossy papers the ratio is somewhat greater, varying with different papers up to about 1 : 50. Since few subjects have a greater range than this, it follows that it is just possible, by using the entire scale of the paper, to include the scale of brightnesses in the subject photographed. The limits of *correct* rendering, however, are fixed by the range of brightnesses included in the straight-line portion of the characteristic curve of the printing material. The range of the straight-line portion of the curve, however, is considerably less than the total scale of the paper. Consequently, the total range of brightnesses in the average subject cannot be included in the straight-line portion of the curve; the total scale of the paper must be used at the expense of correct reproduction at both ends of the scale.

Aside from differences in total scale, printing papers differ in the slope of the curve, or what is designated as gamma, and in exposure range. With papers, the maximum contrast, or gamma infinity, of the paper is reached at a very early stage of development so that prints are always developed to gamma infinity and the contrast of the print is not varied by development, as in the case of negative materials. The difference in the time of exposure necessary to produce the faintest visible impression and that required to produce the maximum black which the paper will yield constitute what is known as the *exposure-scale* of the paper. The exposure scale varies with different papers, ranging from 1 : 5 in the case of a vigorous chloro-bromide paper for amateur printing to 1 : 60 or more for carbon or platinum papers. In other words, with a paper such as the first mentioned, an increase in exposure five times that required to produce the lightest visible grey will result in the deepest black the paper is capable of producing, while in the case of a bromide paper 40 to 50 times, and with platinum or carbon, from

60 to 80 times as much exposure will be required to produce the full range of the paper from white to black.

Papers having a short exposure scale are generally spoken of as *contrast* papers and those of long scale as *soft* papers; actually the contrast of a printing paper is not determined exclusively by its exposure scale but by its maximum black and gamma infinity as well.

In printing, the range of light intensities transmitted by the opacities of the negative cannot be greater than the exposure scale of the paper or the gradations in either the highlights of shadows will be lost. Thus if the light transmitted through the various opacities of the negative range from 1 : 50 then to reproduce all of these differences in the print will require a paper having an exposure scale of 1 : 50; if a paper having an exposure scale of 1 : 25 is used only one-half of the scale of the negative will be reproduced in the print and the differences in either the deeper shadows or brighter highlights will be lost. In practice, therefore, we use for printing a paper whose exposure scale is approximately equal to the range of the opacities of the negative from which the print is to be made. The range of opacities in the negative is under the control of the photographer as it is dependent upon the degree of contrast, or gamma, to which the negative is developed.

Consequently, two courses are open: (1) the negative can be made to fit the exposure scale of a given paper by development to the proper stage, or (2) the negative may be developed to a given contrast and the print made on a paper having an exposure scale suitable for the negative. In practice, both methods are followed although the widespread use of developing papers, the exposure scale of which varies widely in different grades, has caused the latter method to be the more widely adopted.

Adapting the Paper to the Negative.—In Fig. 160, photograph *a* and its accompanying graph illustrate the condition resulting from the use of a long scale paper on a negative with a shorter scale of tones. It will be observed that since the available scale of the printing medium is so much greater than the negative, the use of such paper restricts us to a scale ranging from a white to a grey. Thus, if the densest highlight of the negative is rendered as white, the deepest shadows are grey, rather than black, while if the exposure is adjusted so as to render the shadows black, the highlights of the print are degraded. In either case, the result is smudgy, smoky, with a washed-out appearance lacking in contrast and vigor.

In the same figure, *b* and its accompanying graph represent the

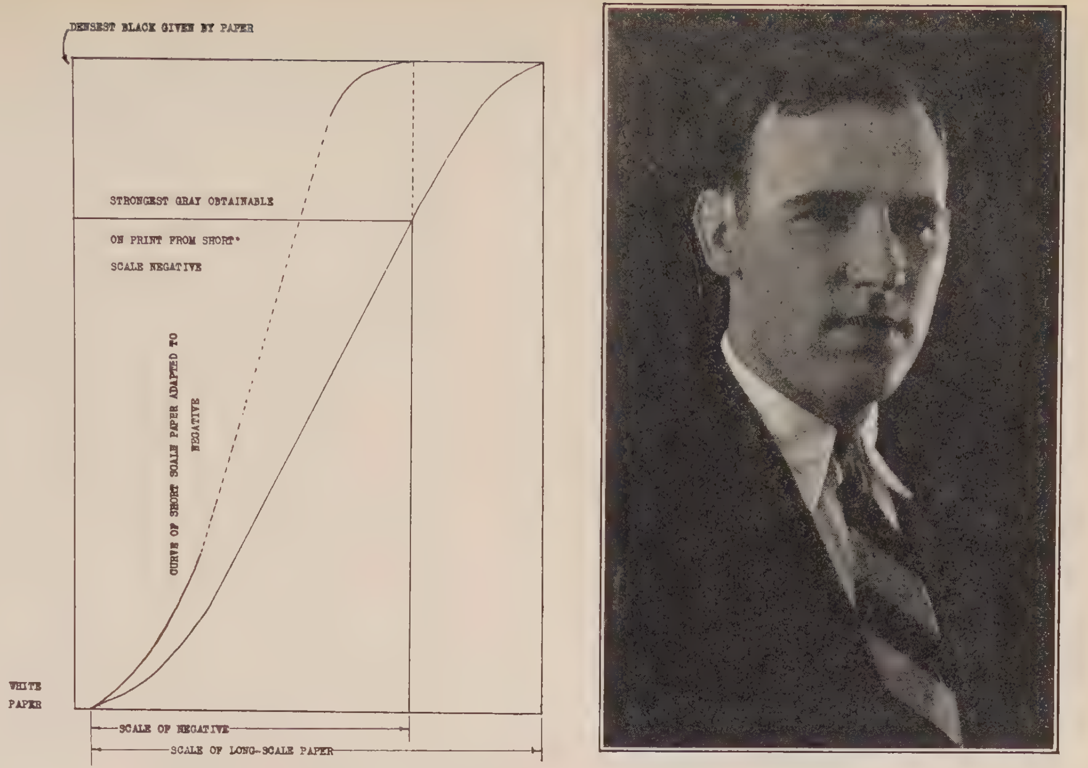

FIG. 160*a*. Adapting the Scale of the Printing Paper to the Negative

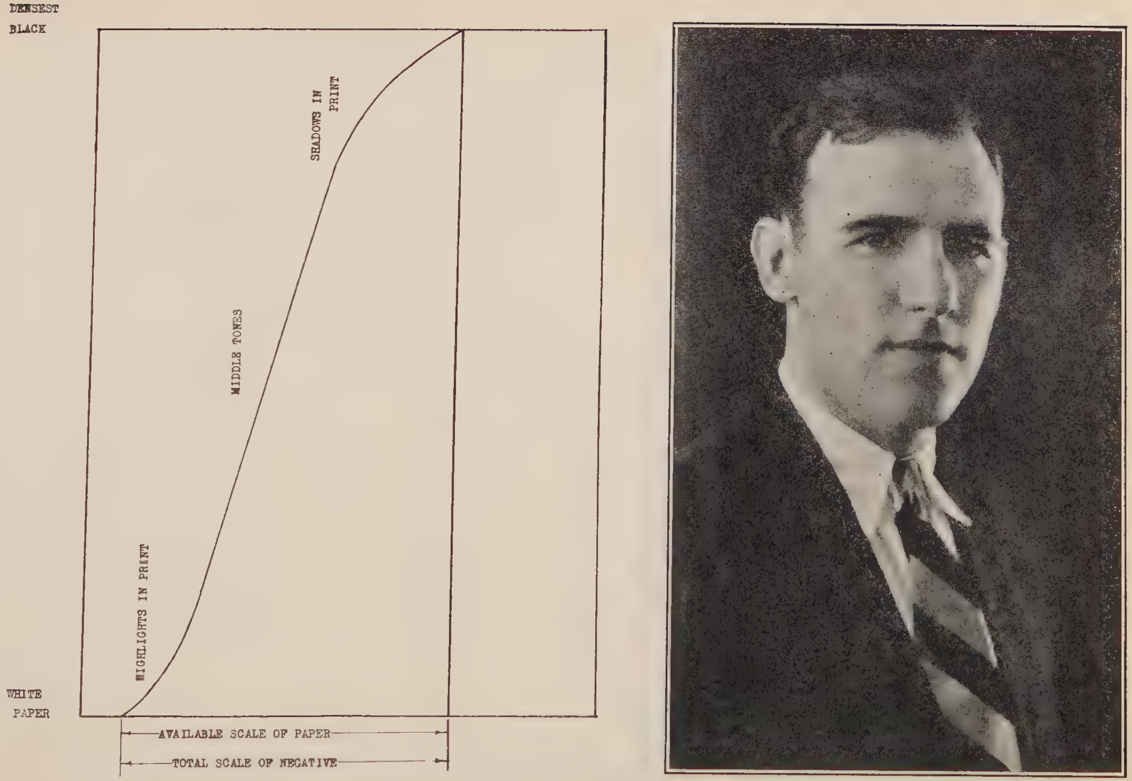

FIG. 160*b*. Adapting the Scale of the Printing Paper to the Negative

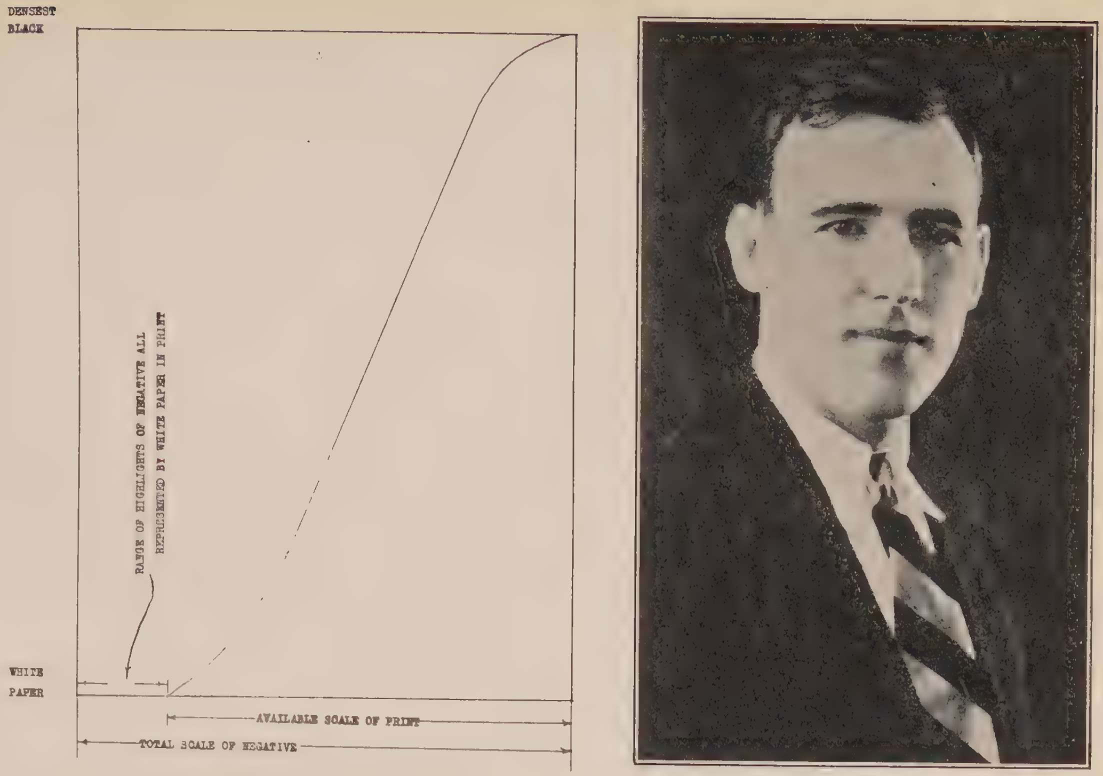

FIG. 160*c*. Adapting the Scale of the Printing Paper to the Negative

condition resulting from the use of a paper having approximately the same scale of tones as the negative. In this case, we have the densest highlight of the negative reproduced as white in the print and the deepest shadow as black, together with a full scale of intermediate tones, the whole resulting in a print with a pleasing gradation from light to dark which impresses us as being natural and proper.

If, however, on a negative with a long scale we make use of a short scale paper we have the result represented in Fig. 160*c*. In this case, we must loose some of the tones, for the limited range of tones available with the particular printing paper is insufficient for the long scale which the negative possesses. Hence we must reproduce the middle tones and shadows correctly and sacrifice the highlights, or we must expose long enough to render the highlights properly and sacrifice all detail and tone in the shadows.

We see therefore that for faithful reproduction of the tones of the subject the scale of the printing medium must approximate to that of the negative and allow us to make the most of the full scale of tones available in a paper print. Now, the three negatives from which these prints were made represent respectively short, normal and long-scaled negatives produced by short, normal and prolonged development. They are, in other words, what would be termed " flat," " normal " and " hard " or contrasty negatives. Now for *a* we have used what is termed in ordinary parlance a soft paper. The result is, as can readily be seen, a lack of vigor owing to the fact that the range of tones in the paper is greater than that of the negative. Consequently we must employ a paper having a shorter scale, or one termed " medium," " normal," or even " contrast " or " hard." In *c* we have a negative with a long scale, or what would be termed a " contrasty " negative, which we have printed on a short scale paper, or in everyday language, a " contrast " paper, the result being excessive contrast together with the loss of proper gradations in the highlights or in the shadows. We must therefore employ a paper with a longer scale of tones in order to make use of the full range of tones in the negative.

The golden rule for selecting the proper grade of paper is, therefore: *Observe closely the degree of contrast in the negative. If the contrasts are correct, use Medium or Normal paper. If the contrasts are excessive, use Soft paper, while if the negative is lacking in contrast, use a Hard, Contrast or Vigorous paper.*

Developing Papers.—Developing papers for positive printing may be broadly divided into two classes; bromide and chloro-bromide. The former is a fast emulsion consisting essentially of silver bromide and corresponds very closely to that of negative emulsions except as regards speed; the latter is a much slower emulsion in which silver chloride is the predominant halide. Aside from the use of silver chloride as one of the sensitive halides, the essential difference in negative and positive emulsions for development is the lower sensitivity and finer grain of the latter, arising from the fact that in the preparation of emulsions for positive printing, digestion plays a relatively unimportant part and from the much lower concentration of the emulsion.

Exposure.—While daylight may be used for exposure, artificial light is preferable, owing to its greater uniformity and also to the fact that daylight is much too rapid for the best results, except where very dense negatives are involved. Practically any artificial light is usually suitable but electricity or gas are naturally more rapid and convenient in use than any of the others. Nevertheless, the common oil lamp, acetylene, or pocket flash lamp may be used when for any reason the former are not available. Magnesium ribbon also forms a very satisfactory illuminant, small lengths of from one half to two inches being used at a foot from the negative. Whatever the illuminant chosen, the distance between the illuminant and the printing frame should be standardized so that it is always the same. This distance must be at least equal to the diagonal of the negative in order to secure even illumination, unless more than one light is used. Far more satisfactory than a printing frame, however, is one of the many types of printing machines which are obtainable in a wide variety of styles and prices. A simple machine made by the Eastman Kodak Company, especially for amateur use, is illustrated in Fig. 161. This printer carries a 60 watt electric bulb and a small ruby pilot bulb. The negative is placed in position on the plate glass top and the paper placed over the same. When the platen is brought forward, the two are pressed into perfect contact and at the same time the ruby light goes out and the white light for exposure comes on. Releasing the platen switches out the white light and turns on the ruby bulb. This machine is one of many similar instruments which work on the same principle varying in details according to the requirements of the amateur, the photo-finisher or the professional photographer.

Correct exposure depends upon: the density of the negative, the speed of the paper, the strength of the light and the distance of the negative from the light. Simple instruments[1] have been devised for measuring the density of the negative and from this determining the proper time of exposure but on the whole this is not so simple, nor so accurate as simply a test strip exposed and developed under actual working conditions, since so many varying factors alter the time of exposure. When once the correct exposure is found, this number together with the paper used may be placed upon the negative envelope and will serve as a guide for future exposures so long as the other factors remain constant.

Exposure is really determined by development and we will have occasion to again refer to the subject shortly.

Developers.—There are countless numbers of formulæ for developers for both bromide and chloro-bromide or gaslight papers, but the following two are as good as any, although it is perhaps simpler to follow the formula advised by the manufacturer. The first formula, however, may be considered as a standard developer for gaslight papers since it is that advised by almost every maker of such papers in America. The second formula is that of Wellington and Ward and is designed for use with bromide papers for which it is especially suitable but the writer has used it with various makes of gaslight paper with perfect success.

Standard Metol-Hydrochinon Developer

Metol	15	gr.	.75	gm.
Sodium sulphite (dry)	½	oz.	11.5	gm.
Hydrochinon	60	gr.	3	gm.
Sodium carbonate (dry)	½	oz.	11.5	gm.
Water	40	oz.	1000	cc.

Potassium bromide from 5–20 grains according to tone desired. (.25–1 gm.)

For convenience in compounding Mr. L. I. Snodgrass recommends that the developer be made up in three stock solutions: one containing the metol and half the quantity of sulphite, the other the hydrochinon with an equal amount of sulphite, and the third the sodium carbonate; the three stock solutions being mixed in the proper proportions to produce a developer adapted to the work in hand. This method has the added advantage that the keeping quality is better than when the alkali is incorporated with the developing agents. The following is the formula recommended by Mr. Snodgrass and the manner of dilution for typical soft, normal and hard-working developers:

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[1] As, for instance, the Sanger-Shepherd Density Meter.

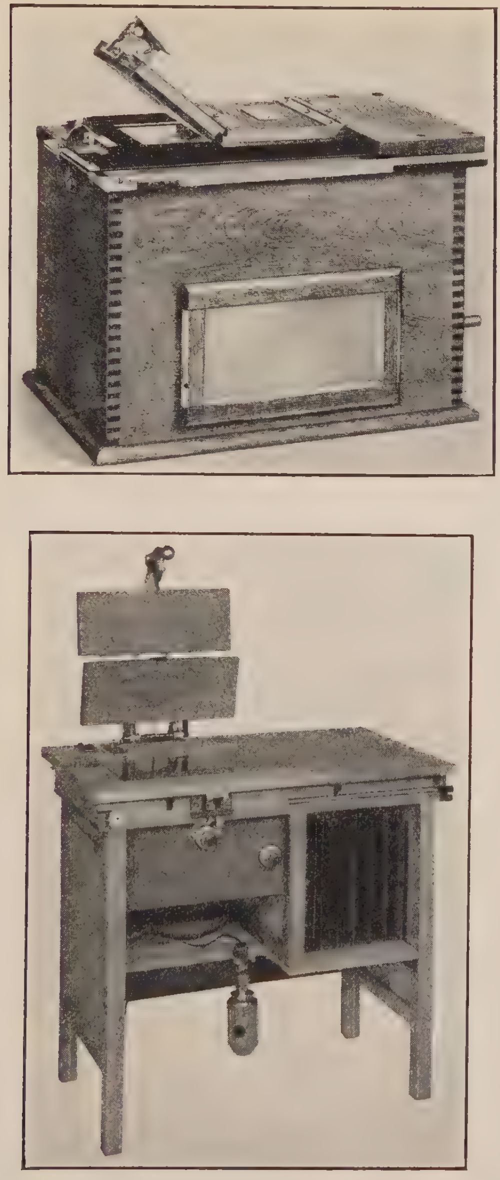

FIG. 161. Printing Machines for Amateur and for Professional Use

	A		*B*		*C*	
Metol	2.5 gm.	45 gr.	....	....	....	....
Sodium sulphite (dry)	18.0 gm.	¾ oz.	18.0 gm.	¾ oz.	....	....
Hydrochinon	....	....	10.0 gm.	180 gr.	....	....
Sod. carbonate (dry)	....	....	....	....	36.0 gm.	1½ oz.
Water	500.0 cc.	20 oz.	500.0 cc.	20 oz.	500.0 cc.	20 oz.

For	*A*	*B*	*C*	Water
Soft developer	3 parts	1 part	1 part	7 parts
Normal developer	1 part	1 part	1 part	3 parts
Contrast developer	1 part	3 parts	3 parts	5 parts

These proportions may be further varied within reasonable limits to secure the effect desired. If too much of stock solution *B* is used the print will have a brownish tint, while if too much carbonate (Solution *C*) is used fog will be produced. Within these limits, however, the developer may be varied to the degree demanded by the work in hand.

Wellington Amidol Developer for Bromide Paper

Sodium sulphite (dry)	325 gr.	17.2 gm.
Amidol (Diaminophenol)	50 gr.	2.8 gm.
Potassium bromide	10 gr.	.56 gm.
Water to make	20 oz.	500 cc.

Amidol does not keep well in solution and the above developer should be used if possible the same day or at least within three days of mixing.

The Safelight.—Development should be conducted in a safe light. If there is any doubt concerning the safety of the light, lay a sheet of paper under the same in the position ordinarily occupied by the developing tray and expose the same for a minute, then develop for a minute in total darkness. If there is any indication of fog, the light is unsafe and should be reduced in volume with a sheet of postoffice paper or a new safelight should be introduced. An excellent lamp for developing is shown in Fig. 25. For gaslight paper, the proper screen is the Wratten Series 00 and for bromide Series 0. Plenty of light may be used but it should be safe. Either of the above screens when used with a 16 candle power electric light will be found perfectly safe and will give an ideal light by which to work.

Development.—The development of prints is not essentially different from that of negative materials but certain factors which are relatively unimportant in negative development become of considerable moment in the development of emulsions on paper. The factors of diffusion and absorption of the developing solution by the gelatine film become much less important, while development takes on more of the character of the so-called "physical" development, i.e., the reduction of the silver from a solution which interacts with the developer. This alteration in the character of development is not due, however, to the use of an accessory solution depositing silver, as in actual physical development, but to the solvent action of the sodium sulphite of the developer on the fine-grained silver bromide and silver chloride.

As silver chloride and the fine-grained silver bromide of paper emulsions are more easily reduced by developers than the coarser grained silver bromo-iodide of negative emulsions, the reducing energy of the developer must be less in order to prevent fog. Hence the use of a soluble bromide in paper developers. The use of a soluble bromide in the developer has much the same effect as with negative materials. The inertia point shifts to the left with the time of development and the shape of the characteristic curve changes. Owing to the fact that the maximum contrast is reached very quickly, there is a tendency, particularly in bromide printing where development proceeds more slowly, to remove the print too soon so that the maximum richness of the deposit is lost. The alteration which takes place in the character of the curve is graphically shown in the following Fig. 162 taken from the paper by Mees, Nutting and Jones of the Eastman Research Laboratory.[2]

It will be observed that there is a vast difference between the curves. One is seriously distorted and the straight line portion is very short, practically non-existent, while full development has given a curve showing a straight line portion of considerable length. This condition obtains when bromide and the slow grades of professional gaslight papers are under developed. The condition is somewhat different in the case of a rapidly developing paper such as Velox or Cyko in which case the maximum contrast is reached in a very short time and times of development shorter than this show serious mottling and irregularity. The golden rule in developing both gaslight and bromide papers is then: *Develop to finality or as far as development may be carried without producing fog.* The exposure will then determine the darkness of the print.

Factorial Development.—This condition is most easily secured by factorial development in the case of papers which develop slowly as bromide and professional chloro-bromide papers and by simple time methods in the case of the rapidly developing gaslight papers. As in the case of plate development the factorial method takes care of the variation in temperature of the developer, and it also affords an accurate indication of the rate of development. Since it is customary to develop several prints, one after another, in the same volume of developer which thus becomes weakened by use the time of development grows longer and this is a factor difficult to determine by the method of development by inspection as commonly employed. Another point in favor of the factorial method is that, provided the proper factor is chosen, development is carried to infinity and the maximum quality which the paper can give is obtained. Still another point in its favor is that it makes correct exposure absolutely necessary as a print which is over exposed will be too dark when developed by the factorial system, while in development by inspection, the print would be removed from the developer when the proper depth had been reached, thus resulting in under development and loss of print quality.

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[2] "The Sensitometry of Photographic Papers," Communication No. 21, Eastman Research Laboratory, Abridgments, vol. I, p. 68, *Phot. J.*, 1914, **54**, 342.

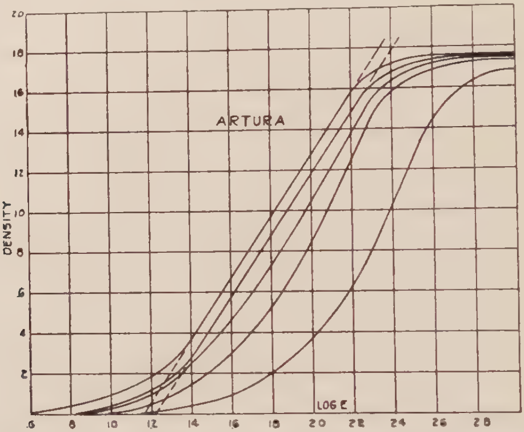

Fig. 162. Effect of Time of Development upon the Characteristic Curve of Paper Emulsions

The Proper Factor.—The proper factor seems to be entirely a matter of the developer and does not seem to be influenced particularly by the paper used. Thus, Kodak, Wellington, Barnet, and Illingworth bromide papers have been developed in the Wellington formula, given above, with perfect success using a factor of 15. In fact, factors from 10 to 20 give practically identical results except that less exposure and longer development is required for the higher factors and in practice 15 may be chosen as a good average, since it is midway between the minimum and maximum useful factors.

The proper factor for any developer may be estimated by exposing strips of paper under the negative for various times and developing the same in the developer for various times and observing accurately the time of appearance of the image. The time of development divided by the time of appearance gives the factor:

$$\frac{\text{Time of development}}{\text{Time of appearance}} = \text{factor}.$$

The following is taken from tests conducted with the Eastman Amidol formula.

	Print No.				
	I	II	III	IV	V
Exposure (seconds)	11	15	18	27	38
Time of appearance (seconds)	15	14	14	13	9
Time of development	300	210	168	104	54
Factor (nearest)	20	15	12	8	6

Prints I, II, and III are practically identical, while IV and V show marked falling off in richness of blacks and in contrast. The proper factor then is somewhere between 10 and 20, so 15 may be used as a standard since it is the average of the two. Time and material spent in determining the factor for any developer will be well repaid in the shape of better and more uniform print quality.

With very rapidly developing gaslight paper the factorial method may be used but owing to the rapid appearance of the image in the developer it is rather more difficult to employ and simple development for the times indicated by the manufacturers in their instruction sheets inclosed with the paper is perhaps the best solution. Care should be taken, however, to keep the developer as nearly 65° F. as possible and to use the same for only a limited number of prints.

The Short Stop.—While prints may be rinsed in water immediately following development and then placed directly in the fixing bath, in commercial establishments and other places where it is desirable to develop several prints before transferring the same to the fixing bath, the prints upon removal from the developer are immersed in a bath of acetic acid, which is termed the "short stop." In this bath, development is instantly checked and the print may be left while several others are developed and then the entire batch transferred to the fixing bath at one time. In some large commercial establishments, it is customary to develop prints and leave them in the short stop until a considerable quantity have collected, when they are fixed together and washed. Such a "batch" may number from one to three hundred prints and is usually governed by the size of the fixing tanks and the capacity of the automatic washers. The formula for the acid short stop is as follows:

Water to make	64 oz.	1000 cc.
Acetic acid 28 per cent (Comm.)	4 oz.	62.5 cc.

Fixing.—Prints require to be thoroughly and completely fixed. Ten to fifteen minutes' immersion in a standard acid fixing bath is sufficient, provided the "hypo" has complete access to the surface of each print. To ensure the latter condition, the prints should be constantly turned over and over so that the hypo may be able to reach each and every print. Merely leaving the prints immersed in a sufficient quantity of fresh acid fixing bath of proper strength for an indefinite time is not fixing and is to be heartily condemned. The golden rule for perfect fixation of prints may be stated as follows: *Use a fresh acid fixing bath and keep the prints in motion for the entire time of fixation, which should require at least fifteen minutes.* In some commercial establishments, where large numbers of prints are handled in each batch, two fixing baths are used, the prints being fixed in one for ten to fifteen minutes and then transferred to the second for a similar length of time. This is a capital plan and is one which might well be adopted by every amateur finisher. Attention might well be called to the fact that the fixing bath should be acid; otherwise, the developer carried over upon the surface of the prints will soon cause it to discolor. Careful draining of the prints as they are removed from the developer and the use of an acid short stop between development and fixing will do much towards keeping the fixing bath clean. There is more danger of overworking the fixing bath with prints than with negatives, since in the latter case the disappearance of the milky backing is an indication of the speed of fixing; whereas, there is no such indication in the case of the fixation of prints. For this reason, it is advisable to keep accurate record of the number of prints fixed in a given volume of solution, in order that the latter may be discarded as soon as the limit of its fixing powers has been reached. One gallon of any standard fixing bath should fix at least a gross 5/7 prints or approximately 5000 square inches of paper surface. As soon as this amount is reached, the bath should be discarded and a new one substituted. Never add new fixing bath to a used solution. Pour out the old bath and replace with new. The following is a good formula for the fixing bath:

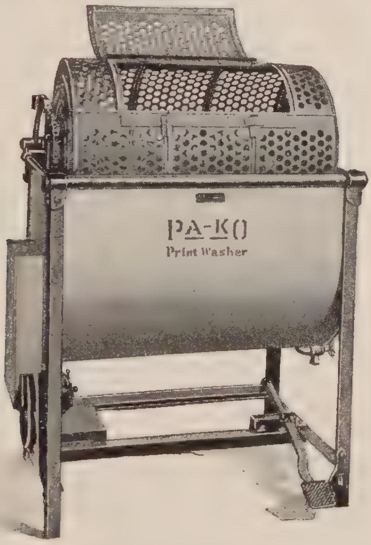

Fig. 163. Electrically Operated Print Washer. (Pako)

"Hypo"	16 oz.	288 gm.
Water to make	64 oz.	1000 cc.

Dissolve and then add the following hardening solution, which may be made up in stock solution:

Sodium sulphite dry	½ oz.	7.1 gm.
Acetic acid 28 per cent	3 oz.	49 cc.
Powd. alum	½ oz.	7.1 gm.
Water to make	5 oz.	78 cc.

Washing.—Prints should be washed for one half to one hour in running water and must be kept separated or they will cling together and the hypo will not be thoroughly eliminated within this time. Several ingenious machines have been introduced for this purpose. Figure 163 shows one of the turbine washers such as are used in large finishing plants. The machine is operated by electricity and has a capacity of about 250 to 300 average size prints, which are kept separated and in motion very efficiently. Another type of washer which is more suited to the amateur and small worker is that illustrated in Fig. 164. The prints are given a swirling motion by the water, which enters on the side so that they are kept well separated. The water passes out through the siphon arrangement in the center which removes the hypo-laden water from the bottom and at the same time owing to its conical shape prevents the prints from collecting in the center. The perfect washing machine does not exist and after all, perhaps the most efficient method consists in constantly transferring the prints by hand from one large tank to another in both of which fresh water is kept running. At any rate, it is well to take no chances with imperfect washing and where absolute permanency is desirable, tests for the presence of hypo should be made by any of the methods previously given in the chapter on Fixing and Washing. The starch-azide test may be recommended as convenient and sufficiently reliable.

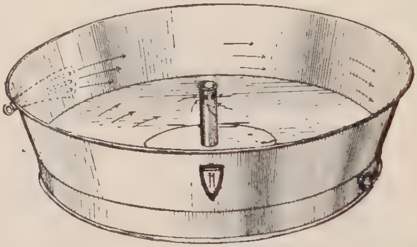

Fig. 164. Centrifugal Water Pressure Type of Print Washer. (Halldorsen)

Drying.—Small batches of prints may be laid out on blotters to dry or stretchers covered with cheesecloth or muslin may be used. Prints which are allowed to become bone dry in such condition will curl considerably and many remove prints when nearly dry and place them between blotters under slight pressure in order to cause them to dry flat. For commercial establishments one of the many forms of drum dryers illustrated in Fig. 165 is recommended. The prints are placed between two broad belts which carry them around a heated drum about three or four feet in diameter. The revolution requires about three to five minutes and when the prints reach the starting point they are thoroughly dried. In some models the drum may be run at different speeds so that single and double weight or thick papers may be dried in one revolution of the drum. There are several dryers of this type on the market. The one illustrated is the Sickle and is shown not because it is any better than any other but merely as an example. Each of the commercial machines has its own distinctive features which should be carefully studied by the intending purchaser in order that he may be sure that he is securing the best apparatus for his particular requirements.

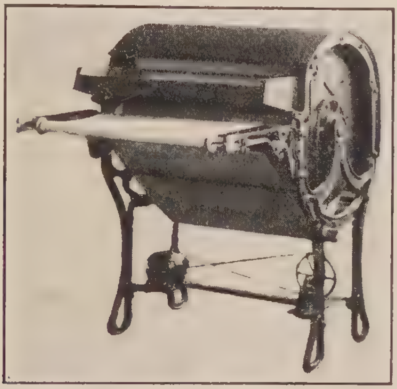

FIG. 165. Rotary Belt Dryer. (Sickle)

Alteration of Contrast.—With a metol-hydrochinon developer it is possible to secure varying degrees of contrast with the same paper by varying the proportion between the two developing agents. Metol being a member of the soft-working class of developers, increasing the amount of metol leads to softer results while increasing the proportion of hydrochinon (which is a contrast developer) leads to greater brilliancy. This is at times very convenient when dealing with negatives having too much or too little contrast for the particular paper required. The three-solution metol-hydrochinon developer worked out by Snodgrass is especially suitable for this purpose as it affords a convenient means of preparing directly from stock solutions a soft-working, normal or contrast developer as required.

With some bromide papers increased contrast may be secured by using a hydrochinon-caustic soda developer as employed for process and photo-mechanical plates but with some papers and, particularly with most gaslight papers, this leads to images of poor color.

When it is required to secure the best possible results from excessively contrasting negatives, without resorting to persulphate reduction or other manipulation of the negative, Sterry's method may be used.[3] By its use soft results may be obtained with the very hardest negatives. The exposed paper is bathed for two or three minutes before development in a solution of potassium bichromate and then developed in the ordinary way. The following stock solution is made up:

Potassium bichromate	1 oz.	91	gm.
Strongest ammonia (.880)	1 dr.	12.5	cc.
Water to make	10 oz.	1000	cc.

For use take one to two drams of the above stock solution to ten ounces of water (12.5–25 cc. to 1000 cc.).

Determine the exposure required to secure the proper detail in the highlights (neglecting the shadows) when developing in the usual way. Then make up the solution as above and immerse the exposed sheet of paper in the solution for three minutes. Wash for half a minute and develop in the regular developer. Development is somewhat slower than ordinarily but the shadows are held back while the highlights come out to proper depth sooner so that the print is softer and has a better scale of values. An acid fixing bath must be used for fixing to avoid stains from the bichromate solution. Various degrees of softness may be secured by altering the strength of the bichromate solution; the stronger the solution the softer the result, other things being equal.

Reduction and Intensification of Prints.—It is not often that one desires to go to the trouble of reducing or intensifying prints as it is usually as simple and more satisfactory to make them over. There are times, however, as in the case of a big enlargement, where expense is an item of importance, when it may be desirable to attempt reduction or intensification before going to the time and expense of making a new print.

As in the case of negatives, prints may be reduced so that the contrasts are increased (subtractive reduction), diminished (super-proportional reduction) or unaltered in contrast, the depth of the print alone being reduced (proportional reduction).

For proportional reduction the following permanganate reducer is quite satisfactory:

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[3] *Phot. J.*, 1907, 47, 170.

Potassium permanganate	7 gr.	1 gm.
Sulphuric acid (10 per cent solution)	350 min.	50 cc.
Water	16 oz.	1000 cc.

This acts rapidly; from 45 to 120 seconds is the average time and it reduces any slight fog which may be present.

For increased contrast (subtractive reduction) the iodine-cyanide reducer is suitable. Owing to its poisonous nature it must be handled with care.

Iodine (10 per cent solution in potassium iodide solution)	403 min.	57.5 cc.
Potassium cyanide (10 per cent solution)	70 min.	10 cc.
Water	16 oz.	1000 cc.

For reduction of contrast ammonium persulphate appears to be the only suitable reducing agent.

Ammonium persulphate	560 gr.	80 gm.
Sulphuric acid	8 min.	1.06 cc.
Sodium chloride (salt)	6 gr.	0.8 gm.
Water	16 oz.	1000 cc.

For use, dilute with two parts of water.[4]

The most satisfactory agent for intensifying prints is chromium. While other intensifiers will produce some increase in depth, the color is nearly always affected and the whites of the print tinted while none is so dependable in use as chromium. In general the operation is exactly the same as for negatives. Particular attention, however, must be paid to the thorough removal of every trace of bichromate before development. The time of washing necessary for this may be considerably shortened by immersing the print for five minutes in a dilute solution of potassium metabisulphite. Redevelopment may be with amidol or with the developer used for the original print, provided it is fresh and does not contain a large amount of soluble bromide. Should the amount of intensification secured the first time be insufficient the operation may be repeated. In this case it is well to use amidol for redevelopment as there is less danger of frilling or excessive softening of the gelatine.

The Glazing of Prints.—Prints with a highly glazed surface can be produced on any of the glossy grades of P-O-P or developing papers. Such prints are best for reproduction and for work of a scientific nature where it is necessary to preserve fine detail. For producing the highly glazed surface, specially prepared iron plates coated with a hard brilliant enamel are generally employed. These are commonly termed ferrotype plates or squeegee tins. The wet prints are placed on the polished surface of the ferrotype plate and brought into perfect contact with the same by the use of a wringer or a hand roller. When dry, they can be stripped from the plate, having acquired as a result of this treatment a highly glazed surface similar to that of the plates on which they were dried. In place of the usual ferrotype plates, celluloid or glass may be used.

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[4] The above formulæ are taken from the paper of Jones and Fawkes on the "Reduction of Developed Prints," *Brit. J. Phot.*, 1921, **68**, 275.

The highest glaze is secured with glass, but owing to the greater danger of prints sticking to the surface so that they cannot be removed without damage, either the ferrotype tins or celluloid are preferred.

The first aim of the worker should be to learn the characteristics of the paper used with respect to glazing. Some papers, which are hardened in the process of manufacture, may be removed directly from the wash water and placed upon the tins; with other papers this would result in complete failure and some form of prehardening is necessary to prevent the prints from sticking to the plates. If the prints are dried and then resoaked until limp in cold water, the gelatine becomes considerably harder and the danger of prints sticking to the plates is largely obviated. Either alum or formaline may be used for hardening the emulsion, in order to prevent the necessity for an intermediate drying, but of the two formaline is undoubtedly the better. In the first place it does not endanger the permanency of the prints, as if not completely washed out in the few minutes wash which should follow immersion in the formaline solution it will evaporate entirely. In addition, it possesses the advantage over alum in that it has no tendency whatsoever to produce iridescent markings on the prints. A solution of 1 oz. formaline to 20 oz. water is sufficiently strong.

If glass is used the plates are first cleaned by soaking for several minutes in weak sulphuric acid (1 oz. commercial H_2SO_4 to 10 oz. water), then rinsed under the tap and scrubbed with plain washing soda, again rinsed and allowed to dry. When dry the glass is coated with *perfectly fresh* ox-gall (1 oz. ox-gall to 40 oz. water). Old ox-gall is worse than useless and will actually cause the prints to stick. The prints are placed face down on the prepared surface, a blotter placed over them and pressure applied by means of a roller until the prints are seen to be in perfect contact with the surface. The glass is then placed in a cool dry place and the prints allowed to become thoroughly dry before trying to remove them. Some may leave the glass completely when dry, those that do not may be removed by inserting a finger nail under one corner and pulling away from the glass.

Lately Callier has recommended that the glass be coated first with a 2 per cent solution of gelatine. When this is dry, a thin film of collodion is superimposed. This collodion is prepared as follows:

Pyroxyline (soluble)	756 gr.	45 gm.
Vasoline oil	96 min.	2 cc.
Amyl acetate to make	35 oz.	1000 cc.

When the collodion has dried the prints are applied as usual and when dry will drop off. There is absolutely no danger of sticking.

Ferrotype tins, however, are more generally employed in this country. With these the danger of prints sticking to the plates is much less than with glass. It is necessary, however, to keep them absolutely clean and well polished. For this purpose a solution of benzol and spermaceti wax, or turpentine and beeswax, is usually employed. Suitable formulas follow:

Beeswax	20 gr.	45 gm.
Turpentine	1 oz.	1000 cc.

Spermaceti wax	20 gr.	45 gm.
Benzole	1 oz.	1000 cc.

A few drops of this are rubbed on the plate with a piece of clean flannel and the tin polished with another piece of flannel or other soft cloth.

Celluloid forms a very suitable substance for glazing although the gloss is not so high as that produced by glass or by ferrotype plates. A special brand known as Glazine, manufactured by the Glazine Pad Company, Hillsborough, Sheffield, England, is supplied for this purpose. With this the danger of prints sticking to the plate is practically negligible. Neither is polishing of any kind required. The writer has used them with perfect success for two years and believes them to be, all things considered, the most satisfactory glazing substance obtainable.

II. Printing-Out Processes

Gelatine Printing-Out Papers.—Gelatine printing-out papers (called P-O-P for short), once almost universally used for positive printing, have been rendered almost obsolete by the modern developing papers and are now seldom employed. There remain, however, some purposes for which they are still unrivaled as, for example, for prints from which half-tone plates are to be made and for photo-mechanical reproduction processes generally. It seems well, therefore, to include some brief directions for the manipulation of such papers.

Printing itself is very simple and calls for but little comment. The printing frame may be loaded and the progress of printing observed in an ordinary room if one takes the precaution not to stand close to a window and does not leave the paper exposed to the direct rays of light any longer than absolutely necessary. For the best result the negative must be one which has received full exposure and development; weak, under exposed or under developed negatives will not make good prints on gelatine printing-out paper and such negatives are best printed on developing paper. Care should also be taken that the negatives are perfectly dry, otherwise a silver stain may be formed which it is almost impossible to remove.

Exposure should be to the strongest daylight available, excepting direct sunlight, which must not be used except with very dense and contrasty negatives. As there is a certain decrease in depth in the processes of toning and fixing, printing must be carried considerably further than would appear necessary from an examination of the picture in the printing frame. The depth to which printing must be carried to allow for this falling off in toning and fixing is easily learned after a few trials and thereafter gives no trouble. After being removed from the frame the prints are placed away from light and under pressure until a number have accumulated and one is ready for toning and fixing. Exposed prints, however, should not be kept from one day to another.

Toning.—Before toning, the prints are washed in running water for a quarter of an hour, or in several changes of water, care being taken that washing is thorough and that each print receives its proper share of washing. Prints which are left lying on one another do not wash properly no matter how long the period of washing; it is essential that they be kept moving, so that each print is exposed to fresh water. Some methods of toning, however, do not require the previous washing.

There are almost innumerable formulas for the toning bath and many variations in the processes of toning. As ordinarily practiced, toning is an operation which requires considerable practice in order to be able to secure satisfactory and uniform tones. There is a method of controlled toning, however, with which even the most inexperienced person can secure agreeable tones and with a high degree of uniformity. The solutions required are a 10 per cent solution of ammonium sulphocyanide, a 10 per cent solution of common salt, a 10 per cent solution of hypo and a gold bath containing 1 grain of gold chloride to each dram of water. The principle is to use a definite weight of gold for a given number of square inches of paper and leave the prints in the bath until the gold has been used up.

The toning bath is made up as follows: Measure out 10 ounces (1000 cc.) of water and add two drams (25 cc.) of the sulphocyanide solution and 1 ounce (100 cc.) of the salt solution. Mix, and add 1 dram (12.5 cc.) of the solution of gold chloride. Label the bottle Gold Toning Bath. Each ounce (28.4 cc.) of this solution contains 1–10 grains (.0064 gm.) of gold which is sufficient for two 3¼ x 4¼ prints. For warm brown tones half to three quarters of an ounce (14.2–21.3 cc.) is enough: for blue tones a little more may be needed. Other sizes may be handled by taking the proper amount for the size of the print.

Now suppose you have ten 3¼ x 4¼ prints to tone. Measure out 5 ounces (142 cc.) of toning bath and put the prints directly into it without washing. Continue to move them around in the bath until no further change of color can be observed. The final stage is when the surface looks cold and slaty blue. They are then removed, washed, fixed and again washed and dried.

Instantaneous Toning.—Another certain method of securing uniform tones is the so-called instantaneous method. Four stock solutions are required:

A. Ammonium sulphocyanide	1	oz.	100	gm.
Water to make	10	oz.	1000	cc.
B. Gold chloride	15	gr.	133.3	gm.
Water to make	7½	oz.	1000	cc.
C. Sodium phosphate	1	oz.	100	gm.
Water to make	10	oz.	1000	cc.

D. Saturated solution of borax.

Mix for ten 4 x 5 prints (200 sq. inches),

A	1	dr.	10 parts
Water	1	oz.	80 parts
B	½	oz.	5 parts
C	1	dr.	10 parts
D	2	dr.	20 parts

The prints, which should be only one shade darker than the desired shade, are put directly in the toning bath without previous washing. On entering the bath they first turn red, then a dark purple which is almost black in the deepest shadows. No matter how much longer they are left in the bath no further change takes place. As soon as toning is seen to be complete, the prints are fixed or removed to a tray of clear water until ready for fixing.

The advantages of these methods over those commonly advised are obvious as all uncertainty is removed and the operation can be worked at night by artificial light which is impossible in the ordinary way. The editor of *American Photography* remarks that a large number who have given it a trial found it to work perfectly.[5]

Black Tones with P-O-P.—Black tones can only be secured with P-O-P by toning with platinum. The following bath should be used:

Meta-phenylenediamine	7 gr.	1.4 gm.
Potassium chloroplatinite	7 gr.	1.4 gm.
Water to make	10 oz.	1000 cc.

This solution must be prepared directly before use as it does not keep at all well. As soon as the desired tones are secured remove the prints and then fix and wash thoroughly. Bluish-black tones may be secured by first toning in a gold bath, washing well and retoning with platinum; the color depending on the depth to which gold toning is carried. The more gold deposited the bluer will be the final result after platinum toning.

When a platinum toner is used, the prints should be immersed before toning in a 5 per cent solution of salt for five minutes, then rinsed and toned. After toning the prints should be immersed for 5 minutes in

Salt	1½ oz.	140.4 gm.
Sodium carbonate (dry)	¾ oz.	46.8 gm.
Water	16 oz.	1000 cc.

Then rinse, fix and wash thoroughly before drying.

Fixing.—After toning the prints are washed for several minutes, then transferred one by one to the fixing bath which consists of a 10 per cent solution of hypo. The prints must remain in the fixing bath at least 10 minutes during which time they must be separated constantly by hand in order that the fixation of each print may be thorough. Fixing is followed by a thorough washing for ½ hour in running water, or in 6 changes of water, allowing 5 minutes for each change, after which the prints are ready for drying.

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[5] The writer is indebted to Fraprie's work *Practical Printing Processes* for these methods of toning.

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CHAPTER XVIII

PROJECTION PRINTING

Introduction.—There has been an increasing tendency on the part of both amateurs and professionals in recent years to abandon the large, bulky and cumbersome camera and its necessary impedimenta and rely entirely upon projected prints from the small negatives where large prints are required. This course has much to recommend it. Photographic materials are now so perfect that given proper care small negatives can be made which will stand considerable enlargement and still compare quite favorably in quality with contact prints from larger negatives, while the convenience of the small, compact hand camera is not to be belittled.

Perhaps the principle of projecting will be clearer from an examination of Fig. 166, in which *A* represents the illuminant (either daylight or artificial light), *B* the negative, *C* the lens, and *D* the easel. The rays of light from *A* pass through the negative *B*, an image of which is formed on the easel *D* by the lens *C*. The distance between the lens and the easel determines the degree of enlargement, the greater this distance the greater the degree of enlargement.

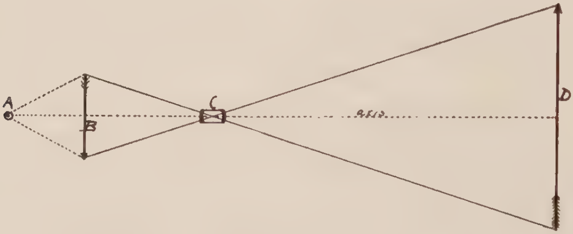

Fig. 166. Principle of Projection Printing

Fixed-Focus Enlarging Cameras.—The simplest form of apparatus for projection printing consists of a box carrying at one extremity the negative and at the other the sensitive paper, with a lens between (Fig. 167). Such cameras are an article of commerce and are intended primarily for the amateur or occasional worker. As they are fitted with cheap single lenses with a small aperture, the time of exposure is relatively long and may easily run into minutes unless daylight and a fast bromide paper are employed. The fixed-focus camera forms a very convenient and satisfactory instrument for the man who desires to make a larger print now and then and who does not care to go to the trouble and expense of employing a more elaborate form of apparatus.

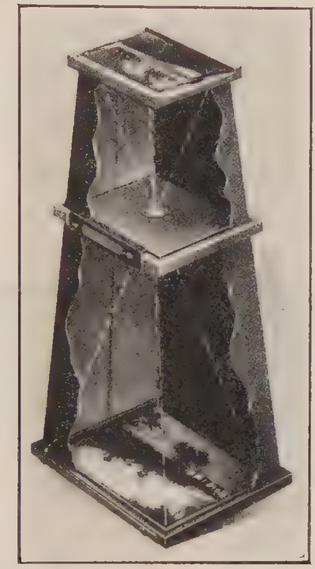

Fig. 167. Box Enlarging Camera

While such instruments may be obtained commercially, there is no reason why the worker cannot make one of his own if he is at all handy with tools, as the construction is quite simple. For this purpose one may make use of the lens attached to his regular camera, providing the fixed-focus enlarging box with a lens flange to take the same, or, if the lens cannot be removed from the camera, fastening the entire camera on a platform within the enlarging camera. As the commercial forms of such apparatus are equipped only with single lenses having a very small aperture it will be readily seen that with but a little time and materials the worker may provide himself with apparatus which is actually superior to the commercial article. The total length of the camera is, obviously, the sum of the distances separating the lens and negative and the lens and sensitive paper. If the positions of the nodes of the lens are known the two conjugate distances can be precisely measured and the partition carrying the lens placed in position without preliminary testing. When the position of the nodes is unknown it is necessary to find the proper position for the lens by experiment. In fact to ensure critical focus it is well in all cases before fixing the lens to make some preliminary tests on a sheet of ground glass placed in the position to be occupied by the sensitive paper.

Apparatus for Projection Printing with Daylight.—There are cameras made especially for enlarging and reducing. These are provided with long bellows extension so that the degree of enlargement, or reduction, may be varied, within certain limits, as required. In Fig. 168 we illustrate a typical camera designed for this purpose. Such cameras are heavy and expensive, occupy considerable space and, moreover, the size of enlargement is limited by the size of the camera. For these reasons other forms of apparatus are to be preferred.

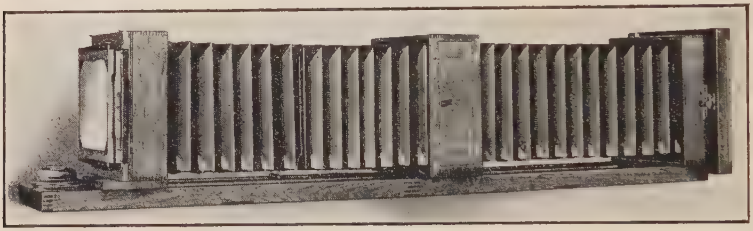

FIG. 168. Daylight Enlarging Camera

The most satisfactory method of employing daylight for projection printing is illustrated in Fig. 169. A window which receives clear unobstructed light from the sky is blocked up, except for a small opening about twice as large as the largest negative to be used, and provision made for attaching an ordinary camera, the reversing back having been previously removed. A platform is built to support the camera and guides or markers placed to show the proper position of the easel. Provision must of course be made for holding the negative and one or two sheets of ground or opal glass which serve to diffuse the light and prevent uneven illumination of the negative. Where clear unobstructed light cannot be secured it is necessary to employ a reflector, as shown in the figure. This reflector must be at an angle of 45° so that it will cast the unobstructed light from the sky onto the negative. This reflector may be of any enameled surface as white paper, or wood painted with a glossy white paint. A mirror is to be avoided. In place of a reflector the ribbed glass known as prism glass may be used, being placed two or three inches before the negative in order that there may be no danger of it being in focus. Daylight has several positive advantages and at the same time disadvantages which prevent its general use. In its favor it may be said that the light is rapid and owing to the perfect diffusion any retouching or handiwork on the negative does not show so prominently as when the light comes from a concentrated source. For this same reason there is less granularity apparent with a high degree of enlargement when daylight is used than when condensers and a concentrated light source, such as the electric arc, are employed. On the other hand, daylight is never constant and exposures are therefore liable to sudden change, which occasions considerable waste of time and material.

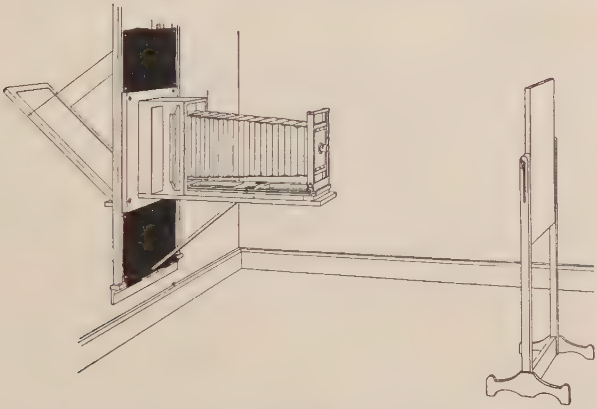

FIG. 169. Projection Printing Apparatus for Use with Daylight

Apparatus for Projection Printing Using Artificial Light.—Owing to the inconstancy of daylight practically all enlarging is now done with artificial light. The typical lantern for enlarging with artificial light is illustrated in Fig. 170. It will be observed that this consists of the illuminant with its light-tight lamp house, either condensers or reflectors for securing the maximum efficiency of illumination from the source used, the negative carrier, the bellows with a projecting lens and lastly the easel. While this is the schematic plan of practically all enlarging lanterns on the market, they naturally vary a good deal in minor details. The construction of such apparatus is not above the capabilities of the average worker who is handy with tools and should he care to use the lens and camera which he has already, the expense of the apparatus may be made almost negligible. Directions for making such equipment have been published many times in nearly all of the journals to which the worker who wishes to build his own lantern is referred for further information.

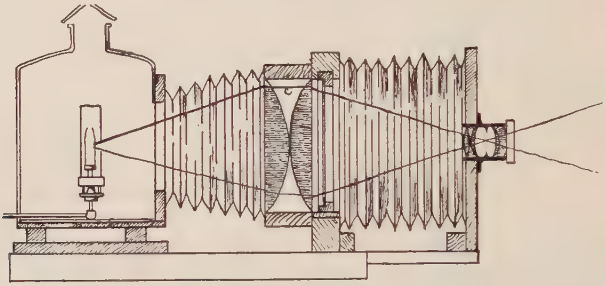

Fig. 170. Enlarging Lantern for Artificial Light

Where condensing lenses are not employed and the light source is one which does not require attention while in use, it may be convenient under certain circumstances to place the light outside of the room used for enlarging. This arrangement has the advantage of increasing the amount of floor space and lessening the effect of the heat liberated by the lights.

Self-Focusing Apparatus for Projection Printing.—A new era in apparatus for projection printing began with the introduction by the Eastman Kodak Company in 1920 of self-focusing projection apparatus in which the image is kept in focus automatically regardless of the degree of enlargement. Other manufacturers have followed the Eastman Company in the field and a number of models are now available. Among these may be mentioned the Callier; Ica; Bordertint; Aldis-Ensign; Sichel's Overton; Butcher's Autoprint; Noxa, besides many others. Directions for the construction of self-focusing projection apparatus have been published in several places (see bibliography).

Illuminants for Projection Printing.—The principal requirements of a satisfactory illuminant for enlarging are that it should be reasonably constant in strength, that it should be strong enough to allow of rapid exposures, and be easily adjusted and convenient in use. Daylight is the least suitable of the illuminants because of its variability. It varies not only from day to day and from hour to hour but may even vary considerably in the short space of a few minutes. For this reason daylight is entirely unsuited to the professional or commercial enlarger who must produce prints of uniform quality, while its use by the amateur means the wastage of much material that might otherwise be saved. The worker who has access to electricity will of course use some form of electric light, and, while it must be admitted that equally good enlargements may be made by daylight or the weaker light sources as acetylene or gasoline vapor lamps, electric light sources surpass all others in general adaptability, since on the whole they are more constant in intensity, more easily adjusted and possess higher intensities than the other sources.

The Mercury-Vapor Lamp.—One of the most satisfactory lights for enlarging is the M-shaped mercury vapor tube supplied by the Cooper-Hewitt Electric Company of Hoboken, N. J. The light is extremely rich in violet rays and is consequently very rapid, so that the slower grades of " gaslight " paper may be used successfully, while for large projected prints the time of exposure is materially lessened. The M-shaped tube gives an even illumination which requires no condensers and, as little heat is produced, it is particularly suitable for summer use. Owing to the M-shape of the tube the illumination is so much diffused that the minimum amount of ground or opal glass is required to secure even uniform lighting. This results in a higher intensity. Undoubtedly the M-tube with a sheet of ground or opal glass as a diffuser forms the nearest approach to daylight of any artificial light and is especially desirable for enlarging from portrait negatives. The mercury-vapor lamp is a rather expensive illuminant for the amateur as its initial cost is rather high, but as it consumes very little current it is not so expensive in the end and in the long run is well worth the cost. Where much enlarging is done and speed and quality and not the initial expense are the prime requisites, then the mercury-vapor lamp may be considered the ideal light.

The Electric Arc.—From the optical standpoint no other light so completely fulfills the requirement of the ideal light surface for enlarging as the electric arc. Whereas all other sources radiate light in all directions, the light from the arc is confined to a small area of about half an inch in diameter on the positive carbon. The light is extremely intense and also very rich in blue and violet rays, especially if flaming carbons are employed. Direct current is by far the most satisfactory for an arc light source as it is more steady, under better control and more economical of current. If alternating current must be used, then it is well to arrange the light in such a way that the carbons are tilted toward the condensers at an angle of about 30° (Fig. 171). When this is done the highly incandescent tip at the extremity of the lower positive carbon is directed toward the condensers, resulting in a higher intensity of illumination. Were it not for its inconstancy and the attention which it requires, the arc lamp might be considered the ideal source for projection printing, but these are factors of considerable importance in practice and consequently we believe that for general purpose work either the mercury vapor tube or gas-filled mazda lamps are to be preferred.

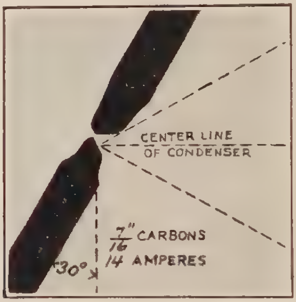

Fig. 171. Proper Position of the Carbons of an Arc Light for Use with Alternating Current

Incandescent Lamps.—Gas-filled lamps of high intensity, such as 500, 750 and 1000 watts, have been extensively used for projection printing since their introduction several years ago and are steadily increasing in popularity. They are very constant and convenient in use, and the color of the light, while not as rich in actinic rays as the arc or mercury-vapor lamp, is nevertheless very satisfactory and the intensity is sufficient for all ordinary enlarging. Special types, known as stereopticon or projection lamps, are now supplied having a small concentrated filament which is almost as satisfactory for use with condensers as the arc. On the whole, however, lamps of this type work better with parallax reflectors than with condensers. The principal objection to the gas-filled lamp is the amount of heat produced and, as in the case of the arc, which develops still more heat, care should be taken that perfect ventilation is secured, otherwise the negative may be melted or warped especially if on film.

Although of lower intensity than electric sources, the Welsbach mantle is well suited to projection printing except for high degrees of enlargement, or with dense negatives, when the time of exposure may be rather lengthy.

Writing in the *British Journal of Photography* (1922, **69**, 767) W. Gard described how he has used for a 3¼ x 4¼ enlarger a 4-volt, 4-watt lamp in connection with a 6-volt, 40-ampere-hour accumulator and for a 4¼ x 6½ enlarger a 6-volt, 12-watt lamp with an 8-volt, 40-ampere-hour accumulator. The lamp is of lower voltage than the accumulator and thus gives a more powerful light. He states that an exposure of 4 seconds was found quite sufficient when enlarging from 4½ x 6½ to 8 x 10 or 10 x 12 using ordinary bromide paper.

Securing Even Illumination without Condensers.—Whatever the illuminant employed it is of primary importance that the negative be evenly illuminated. For this purpose condensers are generally employed with the electric arc and other illuminants approximating to a point source, such as the Nernst lamp or the low volt, concentrated filament, locomotive headlight lamp. For more diffused sources, reflectors are more suitable.

For gas-filled mazda lamps of 500 and 1000 watts the Parallax reflector provides a convenient and efficient means of securing uniform illumination without diminishing the intensity of the source. Fig. 172 shows the construction of this reflector and its appearance when illuminated. It consists of a number of silvered mirrors so placed that the rays of light from the lamp which strike them are reflected out towards the negative in a parallel beam.

A very satisfactory means of dealing with incandescent lamps of lower power is to employ the same in series as shown in Fig. 173 The lights at the corners should be somewhat stronger than that at the center which merely serves to fill in the gap in illumination in the center. This arrangement used with one or two sheets of ground glass should provide perfectly uniform illumination.

Although less powerful than direct light there are several worth-while advantages to the use of reflected light. It is softer, owing to more complete diffusion, and consequently gives softer, more delicate results, with a longer scale of gradation and greater freedom from granularity than a direct source. For the portrait photographer it is particularly advantageous since any retouching or other handwork on the negative does not show up so prominently as when a direct, concentrated source is employed.

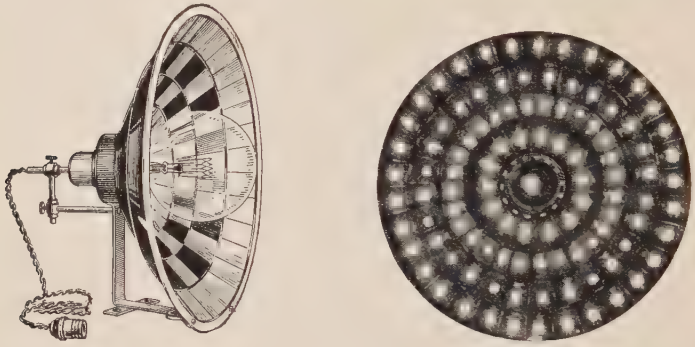

Fig. 172. Parallax Reflector for Use with Incandescent Electric Sources

While theoretically the reflector to be employed should be parabolic in form, in practice any of the forms illustrated in Fig. 174 will be found suitable. The light houses illustrated may be built of thin sheet metal or wood. In the latter case it is well to line the sides adjacent to the lights with asbestos to prevent danger of fire. The reflecting portion should be of sheet iron coated with aluminum paint. Care should be taken that the reflector is not too small or the illumination of the negative will not be uniform. To ensure uniform illumination the reflector should be made at least 3 times the size of the largest negative to be employed. For the smaller sizes a single gas-filled

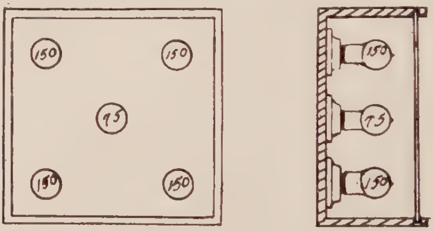

Fig. 173. Securing Even Illumination with Five Incandescent Electric Sources

bulb on each side may be sufficient. For larger sizes, however, it will be necessary to use more than one bulb on each side, or the long tubular lamps as used in window display illumination may be used.

The Condenser in Projection.—With a suitable light source the negative can be uniformly illuminated by means of condensing lenses.

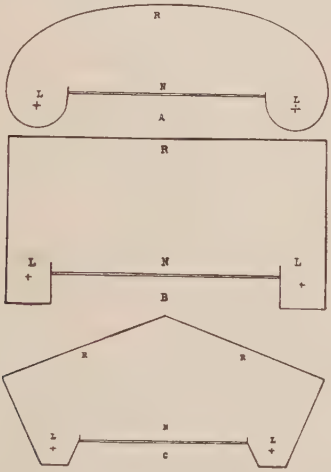

FIG. 174. Forms for the Lighthouse Using Reflected Light. (Wall)

These lenses are of the plano-convex type and are used in pairs, the two convex sides facing one another and separated by a fraction of an inch. The diameter of the condensing lenses must be at least as large and preferably somewhat greater than the diagonal of the largest negative with which they are to be employed. Condensing lenses are supplied in pairs either mounted or unmounted in the following sizes and focal lengths:

Diameter	Focal length in inches	Thickness in inches
4	5½	⅞
4½	5½	1 3/32
4½	6½	29/32
5	6½	1 5/32
5½	8	1 5/32
6	10	1 1/16
6½	10	1¼
8	12	1 15/32
9	14	1⅝
10	15	1 17/32
12	18	2⅜
14	21	2⅝

The focal length of a pair of mounted condensing lenses can be determined from the usual rule governing the focal length of a compound lens system. As the plano-convex lens has only one determinable nodal plane, which lies adjacent to the vertex of the convex surface, the distance between the nodal planes obviously becomes that separating the convex surfaces of the lenses. The expression thus reads:

$$F = \frac{F_1 \times F_2}{F_1 \times F_2 - d}.$$

Where: F = the equivalent focal length.
F_1 = the focal length of lens 1.
F_2 = the focal length of lens 2.
d = the distance between the facing convex sides of the mounted lenses.

The function of the condensing lenses is to collect the diverging rays of light and condense these on the negative, bringing the light rays to a focus in the projecting lens. Thus in Fig. 175 the light rays from the source *E* strike the first condenser and are refracted so that they enter the second condensing lens parallel to one another. In this second condensing lens further refraction takes place, the rays being converted into a converging cone the apex of which (or the focus) lies at, or very near to, the principal nodal plane of the projecting lens, *O*. Thus the rays which in the absence of the condensing lenses would have continued on in straight lines and be lost are bent and made to pass through the lens, so that uniform illumination together with a high intensity is obtained.

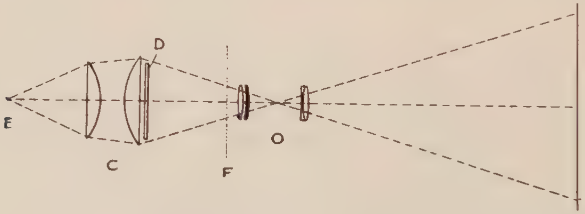

FIG. 175. The Function of the Condenser

From this it is evident that to secure the maximum intensity, together with uniform illumination of the negative, when condensing lenses are used without a diffusing medium, such as ground or opal glass, the light source must be located at such a point on the optical axis that its image, formed by the condensing lenses, is located at the principal nodal plane of the projecting lens. If we ignore the exact nodal planes, this means that the distances *AB* and *CD* (Fig. 176) are conjugate foci of the condenser while the distances *ED* and *DF* are conjugate foci of the projecting lens. As the degree of enlargement is altered the distances *ED* and *DF* will vary according to the rule of conjugate foci (Chapter III, p. 74). With every variation in *ED* : *DF* there will be a corresponding variation in *AB* : *CD*, so that in order to keep the image of the light source in its proper place at the principal nodal plane of the projecting lens the distance *AB* must be varied each time the degree of enlargement is altered.

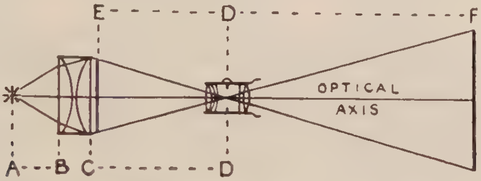

FIG. 176. Conjugate Foci in Enlarging

The problem is thus one of conjugate foci and as such might be calculated mathematically with the aid of the formulas given in an earlier chapter (Chapter III, p. 75). However, owing to the fact that condensing lenses are of cheap construction and entirely without correction, the image of the light source is never a sharp one and in practice such calculations are not of much practical value. One can usually determine the proper position for the light source with sufficient accuracy for all practical purposes from the examination of the circle of illumination as thrown on a sheet of white paper. The character and position of colored fringes or areas of uneven illumination indicate the steps which should be taken towards securing equality of illumination. This matter is illustrated in Fig. 177.

Condensing Lenses with Diffusing Media.—With a light source of small dimensions, such as the electric arc, and in the absence of a diffusing medium, such as ground or opal glass, the image formed at the focal point may be smaller than the aperture of the objective. It is obvious that in such cases the effective aperture (on which the speed of the lens depends) is not that indicated on the mount but that of the light beam which passes through the objective. Thus it may happen that a lens with relative aperture of *F*/4.5 is actually being used at a relative aperture of *F*/11. Therefore the time of exposure would not be altered if the lens is stopped down to *F*/6.3 or *F*/8. However, if a diffusing medium, such as ground or opal glass, be interposed in the path of the light rays, either in front of or between the condensers, this condition no longer applies. One is then dealing not with direct light but with scattered light and in this case the exposure is directly proportional to the lens aperture as in ordinary photography. The ground or opal glass may be placed either in front of or between the condensing lenses. Theoretically placing the diffusing medium between the condensing lenses results in less loss of light from diffusion, but practically the difference is so small as to be almost negligible, while there are other disadvantages which far outweigh this slight advantage. The uniformity of illumination is not nearly as satisfactory as when the diffusing medium is placed before the condensing lenses and in the case of ground glass the grain tends to produce a granular effect which may in certain cases be decidedly objectional and which it is always well to avoid as much as possible. This is due to the fact that the ground glass is much nearer to the focal plane of the negative and therefore more nearly in focus. Therefore with ground glass a position slightly in front of the condensing lenses is advisable. Opal glass being practically free from granularity may be placed between the condensing lenses if desired. Even in this case, however, a position before the condensers is prob-

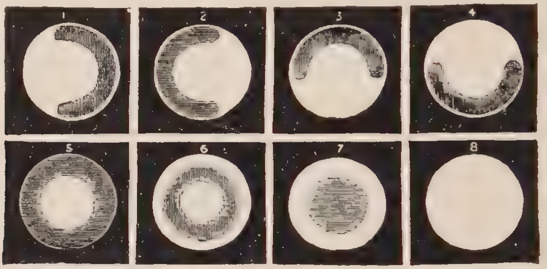

Fig. 177. Adjustment of the Light Source with Condensers

In Figs. 1 and 2 the radiant, i.e., the crater, needs to be properly adjusted laterally; it is too far to the right or left.

In Figs. 3 and 4 it is too high or too low.

In Figs. 5, 6 and 7 it is too near or too far from the condenser.

Fig. 8 shows it to be in correct position, the field being entirely clear.

ably to be preferred. The use of ground glass makes unnecessary the adjustment of the light source each time the degree of enlargement is altered. However, in order to obtain maximum printing speed, an adjustment should be made when there is a considerable difference in the degree of enlargement. By the use of diffusing media, scattered rather than direct light is employed and this, as already noticed, has the effect of reducing to some extent the contrast of the large print as well as its granular appearance. For these reasons the use of diffusing media is always advisable with portrait or pictorial negatives and for those to be enlarged considerably.

The Projection Objective.—A large number of the projection apparatuses on the market, especially those of foreign make, are fitted with objectives of the Petzval type. Aside from its large aperture and excellent axial spherical correction, this type of lens is by no means the best for the purpose, owing to the rapid diminution in the intensity of the image towards the margin and the pronounced curvature of field. Much better is the aplanat, or rapid rectilinear, which, though slower, has a flatter field with more perfect marginal definition. The rectilinear, however, is surpassed by the anastigmat whose superior marginal definition combined with an astigmatically flat field renders it particularly well suited for projection purposes. For use with condensers in conjunction with an arc, or similar source, and without a diffusing screen there is no advantage in the use of a lens having an aperture much larger than $F/6.8$ since this is sufficiently large in most cases to admit the whole of the converging beam of light from the condensing lenses. However, when condensing lenses are used with the ordinary incandescent light, or diffusing media of any kind is inserted in the path of the light rays, a larger aperture may be required in order to secure the full efficiency of the light source, since in this case the image of the light source formed within the projecting lens is larger than before. With completely diffused light sources, such as the Cooper-Hewitt mercury-vapor light, groups of incandescent lamps used with ground or opal glass, totally reflected light or a single incandescent electric light in a parallax reflector, a large aperture is also of advantage in reducing the time of exposure.

Except when condensing lenses are employed the only effect of the focal length of the lens is to determine the length of the apparatus necessary. The longer the focal length of the lens the greater will be the bellows length and floor space for a given degree of enlargement.

With condensing lenses, however, the focal length of the lens must be chosen with reference to the focal length of the pair of mounted condensing lenses. If the focal length of the objective is much longer than that of the condensing lenses, the light efficiency is reduced by loss of light between the condensing lenses as shown in Fig. 178.

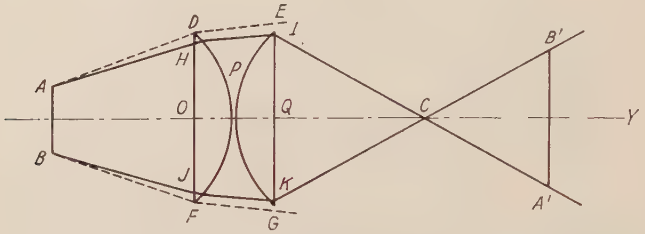

FIG. 178. Loss of Light between Condensers Due to the Use of a Long Focus Lens for Projection. (Candy)

In addition to this loss, under such conditions the size of the light image will be greater than the size of the light, and the aperture of the objective may not be sufficiently large to accept it, which results in further loss. Contrariwise if the focal length of the objective is much less than that of the condensing lenses, the converging power of the latter will be reduced owing to the convergence of the rays between the condensing lenses (Fig. 179). Therefore when condensers are employed the objective used for projection should have a focal length approximately equal to the focal length of the pair of mounted condensing lenses. Exact equality is not required but the two focal lengths should be as nearly identical as possible.

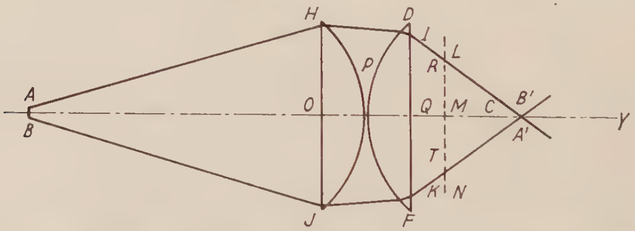

FIG. 179. Loss of Covering Power Owing to the Use of Short Focus Projecting Lens with Condensers. (Candy)

Attention may perhaps be usefully called to the fact that with certain lenses in which the front component has a strong condensing action, so that the "inconstancy of aperture" (Chapter II, page 79) is pronounced, better results are obtained when the lens is turned so that the front component faces the negative.

The Projection Easel.—The easel may be simply a large drawing board of soft wood to which the paper is attached by means of push pins. As a matter of convenience the wood may be covered with heavy "cork lino," a heavy linoleum used for floor covering. This enables the paper to be pinned up with very little pressure. For convenience in placing the paper in position, the easel may be painted white and ruled with heavy black lines for the different sizes of enlargement or in one half inch squares numbered in large figures each way from the center on a vertical and a horizontal line. A further refinement consists in provisions for raising or lowering the easel and for sliding it to the right or left. By this means the portion of the negative used for projection may be brought within the limits of the area marked on the easel for various sized enlargements.

Mr. E. J. Wall coats the easel with a mixture of the following composition which does not dry but remains tacky so that the sheet of paper placed in position and rubbed down will be held in place for as long as required, after which it may be stripped off without difficulty:

Gelatine	407 gr.	53 gm.
Golden syrup	407 gr.	53 gm.
Glycerine	1 oz.	65 cc.
Chrome alum	8 gr.	1 gm.
Water to make	16 oz.	1000 cc.

Any grade of cooking gelatine may be used. It is first soaked for ½ hour in about ¾ of the total volume of water to which has been added the syrup and glycerine, after which it is melted in a water bath by heating to 50° C. (120° F.). Dissolve the alum in an ounce of water. Then make the bulk of the solution up to 15 ounces, add the alum solution and strain through linen. Allow 65 cc. of this mixture to every 100 square centimeters of the easel (about 1 oz. to each 100 square inches). The mixture sets in about 24 hours and the easel is then ready for use.[1]

Perhaps an even more convenient method consists in using a large printing frame. Fig. 180 shows a commercial easel designed for use with printing frames and provided with guides in order that the frame may be returned to the same position when loaded with the sensitive paper as it occupied when focusing. For commercial use where large numbers of prints must be made rapidly with a projector of the horizontal type an easel such as the "Westminster,"[2] illustrated in Fig. 181, is very convenient. The easel itself is swung to the horizontal position for inserting the paper which is fastened in place by clamping over it the hinged sheet of glass, after which it is swung to the vertical position for the exposure.

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[1] *Amer. Phot.*, 1923, p. 717.

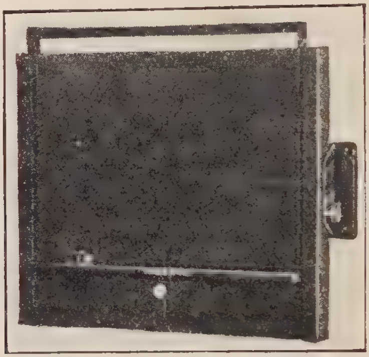

Fig. 180. Ingento Enlarging Easel for Use with Printing Frame

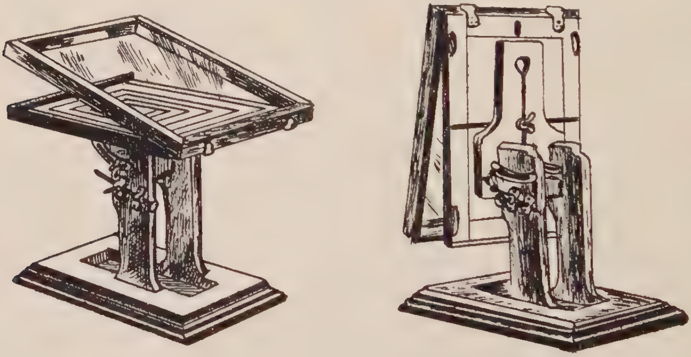

Fig. 181. Westminister Enlarging Easel

With projection apparatus of the vertical pattern the easel becomes a very simple affair. In this case a flat surface of sufficiently large dimensions with a sheet of clean glass free from flaws or two bar weights sufficiently long to keep the sheet of paper flat during exposure constitute all the fixtures necessary for speedy and efficient working.

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[2] Made by Westminster Photographic Exchange, Ltd., 61 Piccadilly, London, W. C., England.

Whatever the form the easel takes means must be provided for altering the distance between it and the projecting lantern and in such a way that the parallelism between the plate and the easel may not be disturbed. For this purpose a grooved track may be made or markers may be placed on the floor to indicate the position of the easel for different degrees of enlargement.

The Negative for Projection Printing.—It is difficult to give any precise definition of the proper type of negative for projection printing since so much depends upon factors for which no definite numerical expression is available. Of primary importance is absolute freedom from physical defects of any kind such as scratches, pin-holes and spots of all kinds, as they are enlarged along with the rest of the negative and become unpleasantly conspicuous in the finished print. While much may be done towards removing such defects by appropriate handwork, such work requires to be done very carefully as imperfections which would not be seen on a contact print are only too prominent when enlarged.

Hunter and Driffield were the first to call attention to the fact that positives obtained by projection possess more contrast than contact prints from the same negative and on the same printing material.[3] Seven years later Chapman Jones [4] investigated the scattering of light by the photographic plate and in 1909 Andre Callier in a paper before the Royal Photographic Society of Great Britain [5] showed precisely how this was responsible for the difference in contrast between positives made by projection and those made by contact printing from the same negative and on identical printing media. He says:

"In projection there is, of course, a scattering of the light transmitted by the negative (Fig. 182). The ray *SN* coming from the light source *S* is scattered in passing through the negative *N*, and only a part of the light coming from the negative can enter the lens. As in the transparent parts of the negative the loss by scatter is nearly zero (owing to the relative absence of reduced silver), it follows that the contrast between the non-scattering parts of no density and the scattering parts of high density will be increased by the scatter. In contact printing this scattered light is not lost, and consequently the contrast is much less than in the case of projection."

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[3] *J. S. C. I.*, 1891, **10**, 98.

[4] *Phot. J.*, 1898, p. 102.

[5] *Phot. J.*, 1909, **49**, 200; *Zeit. wiss. Phot.*, 1909, **7**, 257.

It follows, therefore, that negatives for projection printing require less contrast than those intended solely for contact printing. Owing to the intervention of certain factors, for which numerical expression is unavailable, no satisfactory means exist for determining the difference in contrast which should exist in negatives for projection printing and those destined for contact printing. Here, as in numerous other cases in practical photography, experience is the only safe guide. Fortunately, however, the differences among printing media and the opportunities for control in the operation of printing are such as to largely remove this disability so that it is, to a certain extent, possible to secure from any average negative an enlargement with virtually the same gradation as a contact print.

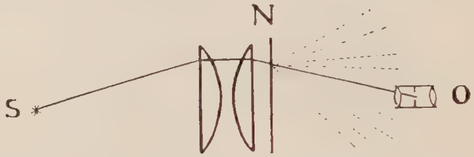

FIG. 182. Scatter of Light by Negatives. (Callier)

In general, however, thin negatives, soft rather than hard, free from fog and from physical defects of all kinds, as well as any undue granularity, are best for enlarging. Recent researches have shown that there is virtually little or no difference among the common developing agents with respect to the granularity of the image. The use of any particular developing agent is therefore not so important as the avoidance of high temperature in developing, fixing and washing: in prolonged drying in hot, humid air and in under exposure. All of these things tend to increase the granularity of the image and are to be avoided with negatives destined for projection printing.

In enlarging from small film negatives, the granularity of the image and defects due to minute scratches and abrasions of the film base can be reduced by immersing the film during exposure in a liquid of approximately the same refractive index as the film base. Suitable liquids for this purpose are glycerine or toluol. A small quantity of either of these is poured on a piece of clear glass and the negative laid down on the layer of liquid so that no air bells are formed. More glycerine or toluol is then poured on top of the negative and this covered with a sheet of glass; both sides of the film being thus covered with the liquid. In this condition the negative is inserted in the enlarger and the exposure made. After the enlargement has been made the film is washed for 15 minutes and dried.[6]

The Technique of Projection Printing.—Assuming the apparatus to be in order and everything ready for use let us consider briefly the technique of projection printing with different forms of apparatus. With daylight or with completely diffused light sources such as the Cooper-Hewitt mercury vapor lamp, reflected light or incandescent lights with reflectors, the operations are simple indeed. The light is first turned on and then the negative inserted in the carrier with its face towards the easel. The projected image is then focused roughly on the easel in order to determine the degree of enlargement. If this is satisfactory all that remains is to focus sharply, cover the lens, or turn off the light, place the sensitive paper in position and expose. However, if the projected image is larger or smaller than desired the easel must be moved nearer to, or farther from, the lens, as the case may be, until it is seen that the projected image is approximately the size desired, after which the image is sharply focused and the exposure made.

These distances from the lens to the easel and from the lens to the negative are conjugate distances and may be readily calculated for any given set of conditions (Chapter III, page 74). The following table, however, will show the conjugate distances for all ordinary degrees of enlargement and for lenses of the usual focal lengths. By "degree of enlargement" is meant linear enlargement. Thus from 4 x 5 to 8 x 10 is two times enlargement, not four times.

When condensing lenses are employed the operations are not so few in number or so simple. In this case the negative should be inserted in the carrier and the image roughly focused to the desired size. The negative carrier should then be removed and the light source adjusted to secure an evenly illuminated field of maximum intensity. These adjustments have been noticed already on page 400 of this chapter. The light source having been adjusted so as to obtain a uniformly illuminated field, the negative carrier is again inserted and the image accurately focused after which the exposure may be made.

Then the paper may be pinned in position and where the easel is not provided with means for altering its position in order that the projected image may be brought within certain previously marked lines,

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[6] Hickman, *Brit. J. Phot.*, 1927, **74**, 87.

TABLE FOR CALCULATING DISTANCES IN ENLARGING OR REDUCING

From The British Journal Photographic Almanac

Focus of Lens	Times of Enlargement and Reduction							
Inches	1 Inch	2 Inches	3 Inches	4 Inches	5 Inches	6 Inches	7 Inches	8 Inches
2..........	4 4	6 3	8 2⅔	10 2½	12 2 2/5	14 2⅓	16 2 2/7	18 2¼
2½........	5 5	7½ 3¾	10 3⅓	12½ 3⅛	15 3	17½ 2 9/10	20 2 6/7	22½ 2 3/16
3..........	6 6	9 4½	12 4	15 3¾	18 3 3/5	21 3½	24 3 3/7	27 3⅜
3½........	7 7	10½ 5¼	14 4⅔	17½ 4¾	21 4 1/5	24½ 4 1/12	28 4	31½ 3 9/10
4..........	8 8	12 6	16 5⅓	20 5	24 4 4/5	28 4⅔	32 4 4/7	36 4½
4½........	9 9	13½ 6¾	18 6	22½ 5 3/5	27 5 2/5	31½ 5¼	36 5 1/7	40½ 5 1/16
5..........	10 10	15 7½	20 6⅔	25 6¼	30 6	35 5 5/6	40 5 5/7	45 5⅝
5½........	11 11	16½ 8¼	22 7⅓	27½ 6 4/5	33 6½	38½ 6 5/12	44 6 2/7	49½ 6 3/16
6..........	12 12	18 9	24 8	30 7½	36 7 1/5	42 7	48 6 6/7	54 6¾
7..........	14 14	21 10½	28 9⅓	35 8¾	42 8 2/5	49 8 1/6	56 8	63 7⅞
8..........	16 16	24 12	32 10⅔	40 10	48 9 3/5	56 9⅓	64 9 1/7	72 9
9..........	18 18	27 13½	36 12	45 11¼	54 10 4/5	63 10½	72 10 2/7	81 10⅛

The object of this table is to enable any manipulator who is about to enlarge (or reduce) a copy any given number of times to do so without troublesome calculation. It is assumed that the photographer knows exactly what the focus of his lens is, and that he is able to measure accurately from its optical center. The use of the table will be seen from the following illustration: A photographer has a *carte* to enlarge to four times its size, and the lens he intends employing is one of 6 inches equivalent focus. He must therefore look for 4 on the upper horizontal line and for 6 on the first vertical column and carry his eye to where these two join, which will be 30–7½. The greater of these is the distance the sensitive plate must be from the center of the lens; and the lesser, the distance of the picture to be copied. To *reduce* a picture any given number of times, the same method must be followed; but in this case the greater number will represent the distance between the lens and the picture to be copied, the latter that between the lens and the sensitive plate. This explanation will be sufficient for every case of enlargement or reduction.

If the focus of the lens be 12 inches, as this number is not in the column of focal lengths, look out for 6 in this column and multiply by 2, and so on with any other numbers.

it is preferable to cover the lens with a lens cap containing an orange light-filter transmitting rays to which the paper is insensitive. This colored screen may be prepared by soaking an unexposed, fixed-out and thoroughly washed plate in tartrazin, naphthol, yellow S, orange G or ammonium picrate, which should be used in saturated solutions and the plate immersed in the dye bath for about 15 minutes, then rinsed and dried. However, where lateral or up-and-down movement of the easel is possible it is perhaps preferable to line the board in squares as previously suggested and center the same with respect to the projected image when focusing. Then the light may be cut off entirely and the paper placed in position by the aid of the numbered squares. We have already shown on page 405 methods which may be conveniently employed.

With automatic focusing apparatus in which the image is always in focus regardless of the degree of enlargement the process becomes as simple as contact printing. In this case one has only to adjust the distance between the projection apparatus and the easel to secure the size of image desired, after which the paper may be placed in position and the exposure made.

Focusing.—There will be no difficulty in focusing as a rule; however, with dense or fogged negatives and at high degrees of enlargement some trouble may be experienced occasionally. In such a case it is well to take an old negative which is quite dense and make a few ragged scratches on it with any sharp-pointed instrument. This may be inserted in the negative carrier in place of the negative and can be focused sharply with ease, after which it is removed and the negative reinserted. Where the exact nodal plane of the projecting lens is known it is possible to construct a focusing scale for the lens and easel using as a basis the distances given in the table on page 410. It is not often, however, that the positions of the nodes are known and in this case the method indicated by Mr. A. Lockett may be usefully employed.[7] All that is necessary to provide any enlarging lantern with an accurate focusing scale, by this method, is the precise determinations of the positions at two different degrees of enlargement, say 3 and 4 times linear, marking the position of the lens standard on the base of the camera for each degree of enlargement. From these two points we can calculate the position for any other degree of enlargement. Since the marks 3 and 4 on the baseboard of the camera indicate the actual tested extensions for that degree of enlargement, when set at position 3 the conjugate focus must be $F + (F/3)$ while at 4 it is $F + (F/4)$. Eliminating F which occurs in both, the distance 3 to 4 is equal to ⅓–¼, or ½ of the focal length of the objective, so that the distance 4–6 on the scale equals the distance 4–3. In a like manner we find that

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[7] *Brit. J. Phot.*, 1924, 71, 171.

Distance 3–4 = distance 4–6,
Distance 3–6 = distance 3–2,
Distance 2–3 = distance 2–1½,
Distance 3–1½ = distance 1½–1,
Distance 6–8 = distance 6–4.

Accordingly the scale of positions on the baseboard of the camera will appear as in Fig. 183. Projection printing with a lantern thus fitted is only slightly less rapid and convenient than with the more expensive automatic focusing apparatus, since nothing more is required than to set the position of lens to scale according to the degree of enlargement required.

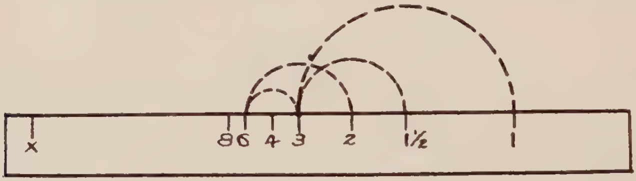

FIG. 183. Graduating Focusing Scale for Enlarging. (Lockett)

Determining Exposures in Projection Printing.—The usual method of determining the proper exposure is by trial with test strips and this is the only certain method in practice. Several methods of determining the proper exposure have been devised by various writers but on the whole they all demand more work and time than the average worker is willing to spend and in practice the method of exposing test strips is almost always used.

Edward S. King[8] and Rev. F. C. Lambert[9] have described methods in which the image thrown upon the easel is examined by a candle and the distance noted at which the candle must be placed in order to obliterate all traces of the image. This distance in inches is then squared and the result multiplied by a correction factor which depends upon the aperture, the paper, etc., and is found by trial for any given set of conditions.

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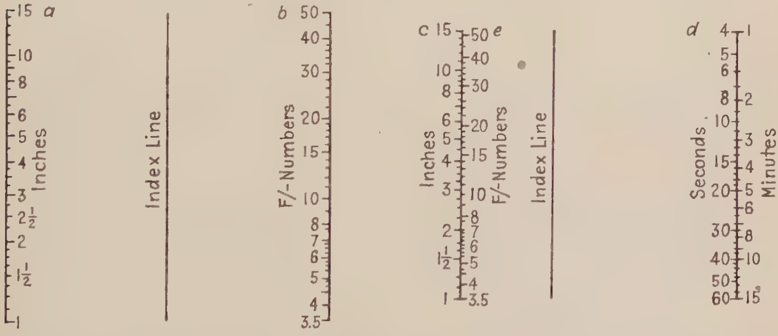
[8] King, *Brit. J. Phot.*, 1906, 53, 188.

[9] Lambert, *Amat. Phot.*, 1921, p. 161.

In practice the writer has found extinction photometers of the Hyde exposure meter and Ica Diaphot type useful and convenient as indicators of the approximate exposure. The projected image is examined through the instrument and the black-glass wedge turned until the details in the highlights are just visible. A little experience will enable the proper point to be reached quite readily. The exposure indicated on the meter is then multiplied by a correction factor which depends upon the speed of the paper, the stop in use, and the color of the negative.[10]

Relative Exposure, Scale and Aperture in Enlarging or Reduction.—When the best exposure has been found for a given negative at a certain size of enlargement, the time of exposure at any other degree of enlargement or reduction is easily found, provided condensers are not used. Perhaps the most convenient method of making such calculations is by the charts described by Capt. S. M. Collins.[11]



In the general problem of exposure there are 3 factors which may all vary; these are: the size of the picture, the aperture of the lens, the duration of the exposure. Any two being known the other can be found. The following scales provide a means of making these calculations. From Chart I is read the alternation in the *F*/number required when varying the size of reproduction to obtain the same exposure. In Chart II, *C* and *D* show the mutual relation of size and exposure if the same *F*/number is retained: and scales *E* and *D* connect the *F*/number and the exposure when it is necessary to change either without varying the size.

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[10] For a very complete system of exposure calculation based upon measurement of the highest density of the negative in a wedge photometer, see article by J. M. Sellors in the *British Journal of Photography*, 1923, 70, 349.

[11] *Brit. J. Phot.*, 1923, 70, 31.

To find the proper diaphragm when it is desired to alter the size of reproduction, but not the exposure, using Chart I run the edge of a ruler from the size of the image to the aperture used. Mark the position at which the ruler cuts the index line. From this position run the ruler to the new size of reproduction. The other end cuts the aperture scale at the proper aperture to employ.

To determine the time of exposure with the same aperture for another degree of reproduction we make use of scales *C* and *D* of Chart II. The straight edge is applied to the scales so that it cuts scale *C* at the size of image for which the proper exposure is known and scale *D* the time of exposure. Mark on the index line the point of intersection as before and join this point to the corresponding size of image on scale *C*. The other end of the ruler will then cut the scale *D* at the proper time of exposure for the new size of reproduction.

The aperture required for any given exposure when that for a given exposure is known may be calculated from scales *D* and *E*. With the edge of a ruler join the aperture on scale *E* with the corresponding exposure on *D*. From the point of intersection with the index line transfer the ruler so that it passes through the exposure required on scale *D*. Then the other end cuts scale *E* at the proper aperture to use.

Introducing Clouds in Enlargements.—In the case of landscape negatives with a bald-headed sky, it is often possible to improve the pictorial effect considerably by printing in clouds from another negative. While there are several ways of doing this, the method to be described is as satisfactory as any and is perhaps the most generally useful. The image of the landscape negative is first focused on a sheet of thin cardboard placed on the easel. On this sheet of cardboard the outline of the skyline is traced with a soft pencil. The cardboard is now removed and cut along the pencil line. The upper piece will serve to mask the sky portion while making the exposure for the landscape while the lower portion will serve to mask the landscape while the cloud is being printed.

This much done, the bromide paper is placed in position and the proper exposure given for the landscape portion masking the sky portion by the sheet of cardboard. It is not often that the sky portion requires any masking, but when it does the appropriate mask is held close in front of the bromide paper and kept in slight up-and-down movement with the cut-out outline in close register with the image.

Now replace the orange cap on the lens and trace lightly on the bromide paper with a soft lead pencil the outline of the sky. Then, without moving the paper, replace the landscape negative by the cloud negative and adjust the latter so as to secure the clouds in the desired position. Next bring the other mask in position so as to cover the landscape portion and make the exposure for the clouds, keeping the mask moving up and down as before.

If the proper times of exposure for the two negatives have been accurately determined by exposing pairs of test strips and developing the same together for the same time, this procedure should result in a satisfactory result.

Of the æsthetic factors in the combination of landscape and sky from separate negatives, it is not within the province of this work to speak. The worker's sense of the æsthetic and his knowledge of nature must ever be on guard in combination printing in order that the result be true to nature and satisfactory to the artistic sense.

Enlarged Negatives.—Where a large number of prints are required it is sometimes more convenient to make an enlarged negative and print from it by contact, while certain printing processes as gum, carbon, and oil require an enlarged negative if prints larger than the original negative are desired.

There are two practical methods: In the first a contact positive is made from the original negative using either the carbon process or a slow dry plate and from this positive the enlarged negative is made in the ordinary way. The second method consists in making an enlarged positive of the size required and from this making the negative by contact printing. Other methods involving the reversal of the image have been advised but as they are hardly suitable for practical use they will not be discussed.

Sensitive Materials.—The sensitive materials used are an important factor in securing satisfactory results. Most inexperienced workers make the mistake of selecting for this work plates of the transparency or lantern slide type. While admirably suited to positives for visual examination, such plates are not well adapted for making either the intermediate positive or the final negative. Far better results are to be had from the use of a medium speed, clean-working plate of normal contrast. The writer has used successfully Eastman Commercial Film, Imperial Fine Grain Ordinary and Cramer Slow Iso plates. The class of plates of which the above are typical representatives are rather faster than ordinary enlarging materials, especially the Eastman film, which is a comparatively fast yet clean-working emulsion. They consequently demand greater caution in handling and exposure, but give better gradation than the contrast-working transparency plates which tend to produce blocked highlights and clear shadows, causing a loss of detail at both ends of the scale, together with excessive contrast as a whole. Extra rapid plates are of course somewhat more difficult to handle and do not give contrast or density quite so readily as those of slower speed. This property may of course become an advantage in dealing with contrast originals, for which plates of the rapid class may be used with advantage, just as transparency plates may be serviceable at times with very weak originals, but on the whole it is preferable to select a clean-working, fine-grained plate with an H. and D. speed ranging from 100 to 150, as the contrast of the final result may be controlled to the extent usually required by alterations in the time of development.

Exposure.—The conditions of exposure will naturally vary with the materials chosen and the equipment of the individual worker. Care must be taken during all operations to see that both the negative and the sensitive materials are completely free from dust, otherwise there is likely to be a fine crop of small transparent spots which completely ruin the result. It is well to call attention to the fact that perfect contact between the two surfaces is essential. The slightest want of contact which may not be observable in the small positive will become serious when enlarged, particularly if the degree of enlargement is considerable. For this reason the light amateur printing frames should not be used for this purpose, but rather the heavy professional frames which are equipped with much stronger springs. It is also of equal importance that the focus be accurate when enlarging. The simplest way of ensuring accurate focus is to replace the usual easel with one consisting of a removable sheet of ground-glass on which the image can be focused by transmitted, rather than reflected light. The use of a ruled test plate in the negative carrier is also to be advised.

The time of exposure will naturally vary with conditions and must be determined by test. For this purpose the first plate should be exposed in strips, giving a range of exposures from which the proper time of exposure may be determined after development. The proper exposure is that which is just sufficient to penetrate the deepest deposits and produce a deposit on the sensitive material. No part—excepting perhaps a small point—of the intermediate positive should be clear glass. Even the highest highlight should show a slight deposit. Nor should the deepest shadows be of any great density. What is required is a soft, almost flat-appearing positive of full detail and delicate gradation. Under exposure is to be avoided and particularly worthy of serious attention is that slight under exposure which tends to give a brilliant, clean-cut result. Invariably this bright, snappy, clean-cut result, for which the inexperienced worker is quite enthusiastic, is the result of slight under exposure and is accompanied with a loss of gradation at both ends of the scale, but more particularly in the highlights. The strip which has received from two to four times the exposure of the snappy-appearing strip (which suggests a good lantern slide) is a better indicator of the proper exposure than the brilliant strip.

Development.—To accurately reproduce the original negative both the intermediate positive and the negative must be developed to a degree of contrast equal to that of the original negative, or what is termed technically a gamma of unity. If it is desired to lessen the contrast of the original, the time of development of either the positive or the negative, or both together, may be shortened so that each is developed to a stage of contrast less than unity. This is a matter far more easily accomplished with exactness by time development than by either inspection or factorial methods.

The Watkins thermo system of development is perfectly adapted to the development of both the intermediate positive and the final enlarged negatives. The thermo system, however, is calculated for a degree of contrast of less than unity (.9), hence if it is desired to secure an accurate reproduction of the contrast of the original negative a longer time of development than that indicated by the tables is required. While I have not calculated its mathematical accuracy, I have secured results sufficiently exact for all practical purposes by developing the positive as directed by the tables, but classifying the plate or film used for the negative one class higher than listed on the table of developing speeds. This opposition of effect, while perhaps not mathematically exact, gives approximately the same degree of contrast as the original negative. To reduce the contrast of the final negative both the positive and the negative may be developed as indicated by the tables, or in the same way, to increase contrast both may be developed as if listed one class higher. In either case, the main point is that one is working under standardized conditions, which enable the source of trouble to be located and the necessary changes in procedure made in a calculable way.

GENERAL REFERENCE WORKS

BAYLEY—Photographic Enlarging, 1923.
FRAPRIE—How to Make Enlargements.
SMITH—Enlargements—Their Production and Finish.
SNODGRASS—The Science and Practice of Photographic Printing, 1923.

CHAPTER XIX

LANTERN SLIDES AND TRANSPARENCIES

The Negative.—In no branch of photography is better technical work required than in making lantern slides and the proper place to begin is with the negative. The clever worker may scrape and make numerous alterations on his negative in such a way that no one will be able to tell the difference in the print, but practically no handwork may be done on a negative from which a slide is to be made, for every touch is magnified from fifty to a hundred times and becomes painfully evident on the screen. Therefore if one is making negatives which may be used for slides it is important to choose a plate of fine grain and reasonably free from mechanical defects. The interior of the camera and the plate holders should be kept free of dust and the plates carefully dusted before loading the holders. Fixing and developing solutions should be fresh and filtered and it is better to fix in an upright tank rather than a tray. After washing, each negative should be cleaned with absorbent cotton to remove adhering sediment and the negative placed in a dust-free place to dry. Too much trouble can hardly be taken in securing the finest quality negative as practically nothing can be done to remedy faults in technique, except, of course, reduction or intensification.

Lantern Plates.—Nearly every plate manufacturer makes at least two varieties of plates for lantern slides. We may divide the commercial plates into three classes:

1. Fast plates for reduction in the camera.
2. Slow, "gaslight" plates for contact printing.
3. Plates of extreme contrast or made especially for warm tones.

Representative brands of the first class are the lantern plates of Cramer, Hammer, Eastman, Agfa, Hauff, Gevaert, Ilford, Barnet, Illingworth, Imperial and Wellington.

Slow lantern plates, handled in almost the same manner as "gaslight" paper, are almost entirely of foreign manufacture. Prominent among plates of this type are the Wellington *S. C. P.*, Imperial *Gaslight,* Illingworth *Slogas* lantern plate, and Gevaert.

Various tones may be secured on most of the lantern plates named above by proper manipulation but there are a few plates which are made especially for the production of warm-toned slides, namely, the Ilford *Alpha*, Gevaert *Warm-tone* and Grieshaber's *Varieta*.

Printing Frame for Contact Printing.—The beginner is advised to start by selecting negatives from which slides may be made by contact printing and, after he has mastered this method and can make a good slide from any reasonable negative, he may take up reduction. For contact printing the negative must not be larger than 3 x 3¾ inches but it often happens that only an area of these dimensions is really wanted from a larger negative and contact printing is then possible. While an ordinary frame may be used it is better to either purchase a special lantern slide frame such as the one illustrated (Fig. 184) or to make one from the following description.

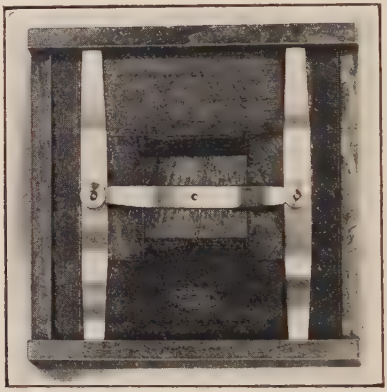

Fig. 184. F and S Lantern Slide Printing Frame

Select a frame two or three sizes larger than any of the negatives from which slides are to be made, say 8 x 10 for 5 x 7. In this is placed a piece of plain glass and over it a piece of opaque paper in the center of which has been cut an opening 3 x 4 inches. Instead of the usual hinged back one of a piece of flat wood, its under side covered with felt, is fitted in. This has an opening in the center measuring 3¼ x 4. A little door of the same dimensions is hinged to one side of the larger back and one of the springs attached to fasten the door and secure contact between the negative and the lantern plate. To use the entire back is taken out and the negative inserted, the desired portion being placed exactly over the opening in the black paper. The back is now replaced and fastened down. The small door may then be opened, the lantern plate inserted and the exposure made. Any number of slides may thus be made from the same portion of the negative without readjustment.

Exposing.—For exposing use any artificial light, preferably electricity. The bulb should be frosted or an image of the filament is liable to fall on the frame. A board should be marked off so that the distance from the frame to the light may always be the same, and variations in the strength of the light eliminated. It is impossible to give any idea as to the length of exposure since lights differ and no two brands of plates have the same speed. The best plan is to make a series of trial exposures for different times on the same plate and from this series pick the one giving the best results. To do this hold a card in front of the frame and uncover an inch of the plate for say two seconds, then shift the card so as to expose another inch and give another two seconds and so on until the whole plate has been exposed and we have four strips the exposures of which are 2, 4, 8 and 16 seconds. In order to make the strips equal and regular the positions of the card may be marked on the outside of the frame. After development and fixation the plate may be examined and the exposure giving the best result readily determined. Before treating development, however, we will discuss the advantages and methods of making slides by reduction.

Printing by Projection.—The writer firmly believes reduction to be superior to contact printing. The definition is better, there is less danger to the negative, or the lantern plate, and any shading to lighten or darken parts of the slide is more easily done. There is also the great advantage of being able to make a slide from a negative of any size when either wet or dry. This last feature is particularly desirable when an advertising slide is wanted in a hurry.

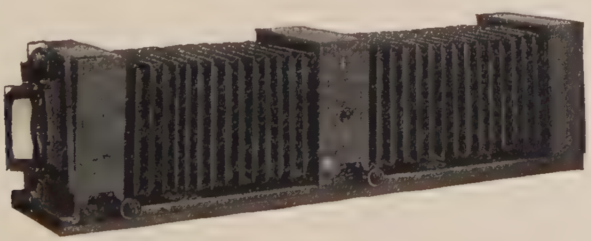

FIG. 185. Century Lantern Slide Camera for Reduction

Slide making by reduction is simply rephotographing the original negative on the lantern plate. Special cameras are available for this purpose (Fig. 185) having at one end a set of nested kits for holding the negative and at the other an adjustable back taking a plate holder of lantern slide size, the lens being fixed in the central compartment. Except for slide making in quantity, their expense is not justified.

Another method consists in blocking out a window in the same way as described on page 392 in the chapter on projection printing and placing the camera on a sliding track facing the negative as shown in Fig. 186. For slide making in quantity, however, artificial light of some kind is far more satisfactory than daylight owing to its uniformity. If desired, artificial light may be used in a similar way, condensing lenses or reflectors being used to secure uniform illumination.

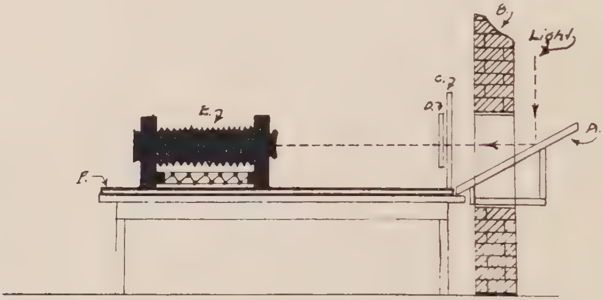

FIG. 186. Slide Making by Reduction Using Daylight

It is more convenient to use for this purpose a camera which focuses from the rear. With a camera focusing from the back it is possible to set the lens at the conjugate focus with respect to the original and the degree of reduction required and focus without disturbing this relation. This is not possible with a camera which must be focused from the front as any movement of the lens to secure accurate focus naturally disturbs both conjugates.

Those provided with a good enlarging lantern may use it for reduction by using a supplementary lens over the regular lens to shorten the focal length, or better by building an extension cone sufficient to provide the amount of bellows extension required. The length of the cone will depend upon the focal length of the lens, the degree of reduction and on the length of the bellows fitted to the machine. The tables of focal distances given in the chapter on projection printing will be of assistance in determining the length of the extension cone.

The most satisfactory method which we have seen for holding the plate in position for the exposure is that described by Mr. D. Charles in the *British Journal of Photography*[1] and illustrated in Fig. 187. The details of construction will be apparent upon a thorough examination of the illustration. In the writer's opinion, sharper focus may be obtained when focusing is done on a ground glass rather than by reflected light. When a ground-glass screen is used methods of Parallax focusing as described on page 524 in the chapter on Copying may be employed to advantage.

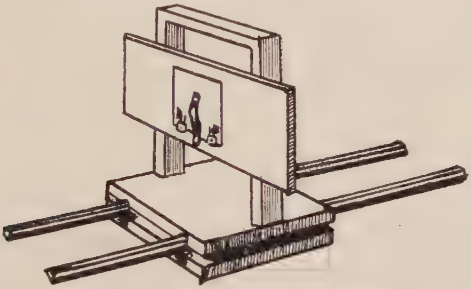

FIG. 187. Device for Holding Lantern Plate in Position When Using Enlarger for Lantern Slide Making by Reduction. (Charles)

As in the case of contact printing, exposures are best determined by test plates exposed in sections. Calculations on the order of those described previously in the chapter on Projection Printing, however, may be useful as a first approximation.

Developers.—A developer suitable for lantern slides should be non-staining, free from fog, and produce an image of good color, fine grain and comparatively high contrast. No developing agent has ever surpassed the old ferrous oxalate in meeting these requirements and it is, therefore, the developer par-excellence for lantern slides and transparencies. It is now seldom used, however, having been replaced by the more convenient and more energetic organic developing agents.

Next to ferrous oxalate one of the best developing agents for transparencies is glycin. The following formula is suitable (*Hubl*):

Sodium sulphite (dry)	600	gr.	125 gm.
Warm water to make	4	oz.	400 cc.
Glycin	480	gr.	100 gm.

Mix well and add gradually:

Potassium carbonate	5	oz.	500 gm.
Water to make	7½	oz.	750 cc.

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[1] *Brit. J. Phot.*, 1922, **69**, 232.

For use dilute with 8–12 parts of water. Slides must be well washed before placing in the fixing bath or stain will appear.

Perhaps the most generally used developer for lantern slides and transparencies is hydrochinon. It has the advantage of giving good contrast and satisfactory color but the quality of the image is not so good as glycin. The following formula is suitable (*Lanier*):

A.	Hydrochinon	77 gr.	10 gm.
	Sodium sulphite (dry)	154 gr.	20 gm.
	Potassium ferrocyanide	922 gr.	120 gm.
	Water to make	16 oz.	1000 cc.
B.	Caustic soda	384 gr.	50 gm.
	Water to make	16 oz.	1000 cc.

For use take 10 parts of *A* to one of *B*. For general use with American plates, however, the developer as made up above may be further diluted with an equal part of water. This developer works with medium contrast. If a hydrochinon developer giving maximum contrast is required the hydrochinon-caustic soda formula given on page 287.

For very fine grain images with the hydrochinon developer add 50–300 grams (385 grains—5½ ounces) ammonium chloride to each 1000 cc. (16 oz.) of the above developer.

Other developers suitable for lantern slides are amidol and metol-hydrochinon. Pyro may be used, but excepting for warm-toned slides, is not so convenient, nor altogether as satisfactory, as the non-staining agents already noticed.

Development.—The writer expresses a decided preference for the Watkins factorial method in developing lantern slides and transparencies. The density of a slide should be determined solely by exposure, and development regulated so as to produce the degree of contrast required. Once the proper factor has been found for the developer and plate in use it is a simple matter to locate errors in exposure and development. The following table shows how to determine the principal defects of exposure and development and to remedy the same.

Fault	Cause	Remedy
Too much density, correct contrast.	Over exposure	Give less but develop to same factor.
Too little density, correct contrast.	Under exposure	Give more but develop to same factor.
Too much contrast, proper density.	Over development	Develop to lower factor. Give same exposure.
Too little contrast, proper density.	Under development	Develop to higher factor. Give same exposure.

The proper factor can be found only by experiment. It is dependent upon the plate, the developer and the degree of contrast required. In all cases it is less than that required for negative development and as a rough guide a factor about ⅗ of the regular Watkins factor may be taken for the first trials.

The proper safelight adds greatly to the accuracy in observing the first appearance of the image and in determining the course of development. For the very fast lantern plates an orange safelight, such as the Wratten Series 0, should be employed; for the slower gaslight plates the Series 00, a bright-yellow, is safe.

Fixing, Washing, Drying.—After development, rinse well in running water and place in an acid fixing bath, those given in the chapter on fixing being entirely suitable. It is important that the fixing bath be kept fresh and acid at all times, otherwise there is liable to be a slight stain on the slides, which, while not particularly noticeable when the slide is held in the hand, will injure the transparency and brilliancy of the highlights when projected. Wash for fifteen to twenty minutes in running water and on removing wipe the surface with a piece of wet absorbent cotton to remove adhering grit and dirt. The slides should then be placed in the rack to dry, leaving at least two inches between each plate in order to ensure a good circulation of air. The use of an electric fan is advisable where possible. It is very important, however, particularly where a fan is used, that the atmosphere be free from dust and perhaps one of the best ways to prevent dust from settling on them is to place a piece of newspaper over the drying rack. Then, if the air is not filled with dust stirred up by cleaning or some similar operation, they will dry comparatively free from dust particles.

Masking.—This is a very important operation, particularly where the subjects are pictorial, as the composition of the finished picture is largely determined at this stage. Of course as much of this should be done in the process of reduction as possible in order to secure the largest possible picture on the slide plate. In nearly all cases the matts used for masking off the undesired portions of the picture should have square corners. It is only occasionally that circular and oval shapes may be usefully employed. Ready cut matts are furnished commercially in a wide variety of shapes and sizes but with most of these the corners are rounded and except in some cases this is nearly always objectionable. Adjustable matts with which any desired size or shape may be obtained are far more generally useful, for.

although they cannot be so quickly applied, there is no need to keep on hand a large number of various sized matts since the proper proportions and size for any requirement may be prepared from the single block of adjustable matts.

Spotting.—After the mask has been fixed to the slide with a little glue and has set under pressure until there is no danger of movement, the slide may be spotted. Spotting is employed to guide the operator in placing the slide in the lantern correctly. The rule to follow in placing the spot is to *hold the slide as it should appear on the screen and place the little square of gummed white paper in the lower left corner.* The lantern operator places the slide in the lantern upside down with the spot acting as a thumb mark.

Binding.—This is the final operation and one at which the beginner is not usually successful. Not that it is a difficult operation, but there is a little knack to it which is readily acquired with experience. The easiest method is to employ four strips, although many experienced hands prefer the continuous strip method. To use the former, begin by cutting a number of strips of binding paper 3¼ and 4 inches in length. The former are used for binding the ends; the latter the sides of the slide. Then take a piece of absolutely clean cover glass (a cleaned-off slide plate) and place it against the masked side of the slide. The binding strip is then moistened and applied to the edge of the slide. First see that the strip of binding tape is placed evenly so that it will fold over regularly and uniformly on both sides of the slide. Proceed in a like manner with the other four sides, then place the slide under pressure for an hour or so.

Advertising Slides.—One is often asked to produce a slide showing both printed matter and an illustration. If the two are copied on a plate suitable for the photograph, then it is impossible to obtain sufficient contrast in the legend, while on the other hand if a process plate is used to reproduce the legend correctly the photograph is excessively contrasty. There are two ways of overcoming this. One way is to make the copy on a plate of low speed which will give fair contrast so as to obtain the very best result for the photograph ignoring the legend. When the negative is dry, cover the photograph with any waterproof varnish and immerse the negative in a ferricyanide-hypo reducer until the lines of the legend are clear. Then after a thorough washing, intensify in Monckhoven's intensifier to secure the proper contrast. When dry the negative may be printed in the ordinary way with good results.

Another way consists in making one negative for the photographic portion and one for the line portion, using the appropriate sensitive material for each. The portion representing the photograph on the process negative is then blocked out by means of opaque while the legend is blocked out on the negative made for the illustration. Means of registration having been provided it is then a simple matter to secure a slide of the proper quality by double printing, first for the illustration and then for the legend.

Toning of Lantern Slides by Restrained Development.—Warm tones of black, brown, red, purple and sepia may be obtained by the use of a developer heavily restrained with soluble bromides and the colors so obtained are usually, in the writer's opinion, superior to those obtained by processes of after-toning. The principle consists in the over exposure of the slide plate followed by development in a developing solution highly restrained with potassium or ammonium bromide or a combination of the two. Not all plates produce satisfactory tones with such treatment and the best tones are secured on the plates advertised as warm-tone by the makers and on the slower brands of slide plates such as Eastman Slow, Wellington S. C. P., etc. The following formula is recommended for the Wellington S. C. P. and when properly used will be found satisfactory for other makes of like nature:

A.	Metol	20 gr.	2 gm.
	Hydrochinon	60 gr.	6 gm.
	Sodium sulphite (dry)	350 gr.	35 gm.
	Sodium carbonate (dry)	350 gr.	35 gm.
	Potassium bromide	20 gr.	0.6 gm.
	Water to make	20 oz.	1000 cc.
B.	Ammonium carbonate	1 oz.	91 gm.
	Ammonium bromide	1 oz.	91 gm.
	Water to make	10 oz.	1000 cc.

Without solution *B* the tone is blue-black. By increasing the exposure and adding correspondingly larger amounts of restrainer warm-brown, sepia, purple and red tones may be obtained. The following table gives the approximate increase in exposure and the composition of the developing solution for the various tones:

Color	Exposure x normal	Developer
Black	Normal	*A* 1 part, *B* — part
Warm-Black	Normal x 1½	*A* 1 part, *B* ⅛ part
Brown	Normal x 2	*A* 1 part, *B* ¼ part
Warm-Sepia	Normal x 3	*A* 1 part, *B* ⅜ part
Purple	Normal x 4	*A* 1 part, *B* ½ part
Red	Normal x 6	*A* 1 part, *B* ⅝ part

The appearance of the slide as it lies in the tray is not an accurate indication of its final color and the best results are secured when development is conducted factorially. The exposure determines the tone to a large extent and development must be regulated accordingly. The proper factor varies from three to five with the above formula. For the Wellington S. C. P. lantern plate a factor of three is recommended, while the writer has found five to be the best for some other brands of plates.

Physical Development.—The advantages of physical development are: facility of obtaining soft slides from harsh negatives, the transparency of the shadows, the unique bluish-black tone and the excellent results obtained by sulphide toning. The precautions to be observed are:

1. Use only fresh plates.
2. Give about double the exposure ordinarily demanded for regular developers.
3. Keep all trays absolutely clean.

The following is the formula of Dr. Mees:

A.	Metol	96 gr.	5 gm.
	Citric acid	96 gr.	5 gm.
	Acetic acid, glacial	1 oz.	25 cc.
	Distilled water to	20 oz.	500 cc.
B.	Silver nitrate	1 oz.	10 gm.
	Water to make	10 oz.	100 cc.

To develop a slide 1 ounce of *A* is poured in a clean glass graduate and 50 minims of *B* added. The exposed slide is placed in the tray, the mixture poured on and kept in motion. During development the silver may be deposited all over the plate but this can be removed by rubbing with wet cotton wool. As soon as the developer becomes brown it should be discarded. Fresh developer must be used for each batch of slides and the trays and graduates cleaned thoroughly each time before mixing in order to insure absolute cleanliness. Physical development is not a process for commercial use but is an interesting method for the amateur who desires unusual effects.

Colors on Direct Development with Thiocarbamide.—The addition of thiocarbamide to a developing solution of metol and hydrochinon restrained with ammonium bromide for the purpose of obtaining a wide range of colors ranging from a delicate violet through red, blue, blue-black and black on lantern slides by direct development was first advised by Wratten and Wainwright, the English firm of plate makers, in 1909. The resultant image is of a very fine quality, with an unusual transparency in the lower tones which is obtainable in no other way, while the range of colors obtainable on slow lantern plates by modification of the exposure, developer or temperature is unsurpassed by any method of toning by direct development. The process is a very difficult one and it is recommended that the student studiously avoid the same, not only until he has mastered ordinary slide making in black and white, but also until he is thoroughly familiar with the production of warm-tone slides by the methods previously described. Experience alone can enable the worker to master the process.[2]

The Toning of Lantern Slides and Transparencies.—With the exception of the hot hypo-alum method, the methods of toning described in Chapter XX may be used for lantern slides as well as prints. Excellent brown tones may be secured by the usual process of indirect sulphide toning; the copper and uranium processes are also widely employed. The toned image, however, leaves something to be desired as regards transparency, the tones produced by after-toning processes never equalling those produced by direct development in this respect.

Probably the finest results in after toning are secured by dye-toning processes. Dye toning has found an extensive application in the motion picture industry but does not seem to be widely employed for lantern slides. For further information on dye-toning methods the reader is referred to *Lantern Slides—How to Make and Color Them* obtainable free from the Eastman Kodak Company, Rochester, N. Y.

Reduction and Intensification of Lantern Slides.—Neither the reduction nor intensification of lantern slides and especially of warm-tone slides is to be recommended as a general rule. For reduction, a weak solution of ferricyanide-hypo may be used, but in the case of warm-tone slides only a slight clearing action should be attempted as substantial reduction alters the color.

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[2] Johnson, *Phot. J.*, 1926, **56**, 159.

Where greater contrast is necessary it is preferable to intensify the negative rather than the slide. However, if for any reason this is undesirable the slide itself may be intensified. The chromium intensifier is satisfactory and convenient for this purpose. For warm-tone slides, however, preference should be given to the following silver intensifier which has the advantage of not altering the color:

A. Metol	88 gr.	9.2	gm.
Glacial acetic acid	1 oz.	50	cc.
Citric acid	176 gr.	18.4	gm.
Water	20 oz.	1000	cc.
B. Silver nitrate	1 oz.	50	gm.
Distilled water	20 oz.	1000	cc.

For use take *A,* 24 parts; *B,* 1–2 parts; distilled water, 24 parts.

The intensifying solution must be prepared fresh for each slide. The *dry* slide is immersed in the intensifier for one to one and a half minutes until the required degree of intensification is secured. If it is allowed to act longer than a minute and a half it begins to work unevenly and produces a blue deposit. Stains on trays, fingers, etc., from the intensifying solution may be removed by acidified permanganate solution or strong hypo and ferricyanide. When intensification is complete the plate is washed in running water for one minute, then immersed in an acid fixing bath for five minutes and finally washed in running water for one hour.

General Reference Works

Fraprie—How to Make Lantern Slides.
Glover—Lantern Slides.
Harris—Practical Slide Making.
Lambert—Lantern Slide Making.
Mercator—Die Diapositiverfahren.

CHAPTER XX

THE TONING OF DEVELOPED SILVER IMAGES

Introduction.—For many subjects a color other than that of the cold neutral black of the ordinary developing papers is desirable and, when the color is selected properly with reference to the nature of the subject, adds considerably to the artistic effect. While of late there has come into being a class of developing papers made for the special purpose of producing warm-black and brown-black tones by direct development and while some few papers may be made by restrained development to produce brown and sepia tones, in general, recourse must be had to toning processes for other colors than the usual black and for warm-black. There are almost innumerable variations in a large number of toning processes producing results of varying quality and differing greatly in adaptability to various emulsions. With some methods of toning, the colors are only slightly inferior to the corresponding images of prints produced by a pigment process such as, for example, carbon. With others, however, the results are not always such as please, much depending upon the suitability of the emulsion and the character of the print, while in some cases the process of toning itself is not above objection. A work of this nature is not the place for a comprehensive review of all of the many toning processes and their modifications. Representative formulæ with manipulative details of the more generally useful methods, however, are included. Those interested in the subject to a greater extent than it is possible to give to it in these pages are referred to the bibliography at the end of the chapter where will be found a fairly complete list of the principal works on the subject published during the last twenty years.

The Sulphur Toning Processes—The Print.—The most widely used processes of toning are those in which the metallic silver of the black image is converted into a colloidal silver sulphide. The colors obtained by such treatment range from purplish-brown, through sepia and various shades of brown, to a disagreeable yellowish-brown. There are a number of processes which fall into this class and these may, for convenience in treatment, be divided into two divisions: (1) the indirect processes in which the metallic silver is first bleached and then converted into silver sulphide by immersion in a bath of sodium, ammonium or barium sulphide; and (2) the direct method in which the conversion to silver sulphide is accomplished in a single solution. Certain differences exist in the nature and working of the two methods which may be more conveniently noticed when we consider the various processes separately. However, as the bearing of the black print on the final result is very nearly identical with all the processes of sulphur toning it is more convenient to consider this subject before proceeding to a discussion of the processes themselves.

The color obtained upon toning depends to a certain extent upon the toning operation itself; much more, however, on the exposure and development of the black print. If increasing times of development be taken and the exposure adjusted in each case so as to produce a print of approximately the same depth, upon toning it will be found that as the time of development is increased the color of the toned print becomes progressively colder in shade. The student is advised to repeat this experiment in order that he may see for himself the exact effect of variations in exposure and development on the color of the toned image. From the series of prints so obtained it should not be difficult to select one which has the color desired. It will then serve as a guide for the development of future prints on the same paper which are to be toned.

Owing, however, to differences in the temperature of various batches of the developing solution, the oxidation of the developing solution when in use, the reduction in its activity with use owing to the restraining action of liberated bromides and to differences in the developing speeds of various batches of the same paper, it is advisable to adopt the factorial system rather than to adhere to a straight timing method. The print to be used for sulphur toning should be developed to a rather high factor—the exact factor to be used depending somewhat on the character of the emulsion and to a certain extent on the color desired. Once, however, the factor has been found which with a given emulsion produces a print which upon toning results in the desired color, duplicate prints of the same quality can be made at any future time. Where the total duration of development is so short as to make the factorial method inconvenient, as is the case with most of the developing papers of the gaslight type which are designed primarily for the use of the amateur, the adoption of a fixed time of development is perhaps the more satisfactory solution. In this case, however, care should be taken not to overwork the developing solution or uniform colors will not be obtained. Indeed for best results it is preferable to use fresh solution for each print, taking for this purpose only sufficient solution to cover the print.

When development is conducted for a definite time, rather than by the factorial method, the amount of soluble bromide present in the developing solution has a very great influence on the resulting color. Therefore when for any reason time development is used the amount of soluble bromides added to the developing solution should be carefully standardized in order that it may be possible to obtain the same tone in the future. Where development is by factor the amount of soluble bromide in the developing solution has but slight influence and the exact amount is therefore relatively unimportant. It is well, however, in most cases not to use very much more than is required to prevent fog.

The nature of the emulsion has considerable influence upon the resulting color. As a rule, the faster the emulsion the colder is the tone obtained with normal treatment while the slower grades tend to produce warm tones. These differences, however, may be, and often are, overshadowed by the exposure and development of the print. Thus, while it may be said that emulsions vary in their tendency to produce warm or cold tones, practically speaking, any desired tone within the range of the toning process used may be obtained when one has a black print of the requisite character.

In the case of sulphur toning by the indirect processes perfect fixation is a matter of vital importance. The investigations of Lumière and Seyewetz [1] have conclusively proved that the staining of the whites met with in sulphur toning by the indirect process is due solely to imperfect fixation. They have shown that fixation is incomplete in a bath of hypo which contains more than 2 per cent of dissolved silver bromide and that prints fixed in such a bath will show a coloration in the whites on toning regardless of the time which they are left in the fixing bath. The authors therefore recommend the use of two fixing baths, one of which has been slightly used while the other is absolutely fresh, and the prints given ten to fifteen minutes' fixation in each bath. It would be well as a matter of principle if workers would accustom themselves to the use of two fixing baths and discard the older of the two at regular intervals depending upon the number of prints fixed, its place being taken by the second bath which is in turn replaced by a fresh solution.

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[1] *Brit. J. Phot.*, 1923, 70, 732.

Sulphur toning processes such as hypo-alum and liver of sulphur (when used in a solution sufficiently strong) which contain a relatively large amount of hypo in their composition are without staining action on the whites of the print provided the fixation has been reasonably complete.

Since these processes contain hypo as a constituent part there is no necessity for thorough washing in order to secure complete elimination of hypo. Thorough washing, however, is a matter of importance when the indirect processes are used since these are quite sensitive to its presence.

The Hypo-Alum Process.—Of the several methods of direct sulphur toning, the hypo-alum process is perhaps the most popular and is extensively used in American studios, practically to the exclusion of all other methods of sulphur toning. It is withal an excellent method for securing such colors as are within its range which may be said to extend from a slightly purplish-brown through various shades of brown to warm-chestnut-brown. It is regular and reliable in action producing agreeable tones and free from the tendency towards extreme warmth of tone which makes it well adapted for many emulsions which with other processes produce disagreeable yellowish tones.

The following is a reliable formula for the hypo-alum toning bath:

Hypo	1 lb.	365 gm.
Hot water......................................	80 fl. oz.	2000 cc.
Alum	3½ oz.	80 gm.

Stir the solution well when adding the alum, then raise to the boiling point and boil for three minutes. Allow the mixture to cool and add the following silver solution, known technically as a ripener, which prevents the bleaching of the prints in the hot toning bath:

Silver nitrate..................................	20 gr.	1.7 gm.
Distilled water................................	1 fl. oz.	30 cc.
Ammonia (.880) sufficient to redissolve the precipitate first formed.		

The solution should be stirred vigorously while the ammonia is being added. It is then added to the hypo-alum mixture and the following solution of potassium iodide made up and added to the bath which is now complete and ready for use:

Potassium iodide................................	40 gr.	3.4 gm.
Water	1 fl. oz.	30 cc.

The prints for toning, which should be slightly darker than required since there is a slight bleaching action in toning, should be fixed thoroughly and rinsed in several changes of water, then immersed in the hypo-alum solution which should be heated to a temperature of about 90° F. (32° C.). The prints are kept on the move while toning in order that there may be no danger of uneven toning from the overlapping of the prints in the solution. At the same time the temperature of the bath is gradually raised to 110 to 135° F. (43–57° C.). The temperature of the toning bath has a slight influence on the color of the toned print, the warmth of tone increasing with higher temperature. The temperature should therefore be regulated with respect to the degree of warmth desired in the finished print. The prints are allowed to remain in the hypo-alum mixture until there is no doubt that toning has proceeded as far as it will go. There is no danger of over toning as the action proceeds to completion and then stops. The time required for toning varies with the temperature of the bath and with the emulsion, varying from 15–30 minutes at temperatures from 110 to 130° F. (43–54° C.).

When fully toned, the prints are removed and the surface swabbed with hot water by means of a tuft of absorbent cotton in order to remove the precipitate of alum which forms and are then washed and dried in the usual way. The toning bath itself should not be thrown away but bottled up for future use as it improves with age.

Several methods of accelerating the action of a hypo-alum bath have been advised. Thermit in the *British Journal of Photography*[2] recommends that the prints after having been fixed in a plain hypo fixing bath be immersed in a 10 per cent solution of sulphuric acid for half a minute, then transferred to the regular toning bath where the action will proceed quite rapidly. W. E. A. Drinkwater in recommending a similar method adds to the sulphuric acid solution a small amount of hypo, as follows:

Sulphuric acid	1 fl. oz.	6.5 cc.
Water	150 fl. oz.	1000 cc.
Hypo	4 oz.	26.6 gm.

Prints transferred from this solution to the regular hypo-alum bath at a temperature of about 110° F. (43° C.) tone completely in a few seconds.

Zanoff's Controlled Hypo-Alum Process.—With the exception of the slight control possible by varying the temperature of the bath, when the ordinary hypo-alum process is followed the tone of the finished print is determined once for all by the exposure and development of the print. Zanoff, however, has described a variation in the usual process by which there is greater control over the resulting tone in the operation of toning. The formulæ for the two toning solutions required are as follows:

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[2] 1922, 69, 126.

I. (*a*)	Hypo	20 oz.	143	gm.
	Alum	2 oz.	14.3	gm.
	Boiling water (distilled)	128 oz.	1000	cc.

Boil two minutes, allow to cool and then add:

	Sodium phosphate	2 oz.	14.3	gm.
(*b*)	Silver nitrate	60 gr.	.95	gm.
	Water	1 oz.	7.8	cc.
	Potassium bromide	180 gr.	2.85	gm.
	Water	1 oz.	7.8	cc.

Pour the bromide solution into the solution of silver nitrate and add precipitate and all to the *cool* hypo-alum bath.

(*c*)	Gold chloride	15 gr.	.24	gm.
	Water	2 oz.	15.6	cc.

Add to hypo-alum bath. This completes solution Number 1.

II. (*a*)	Hypo	16 oz.	114	gm.
	Alum	4 oz.	28.5	gm.
	Water	128 oz.	1000	cc.

Boil five minutes, then cool and add the following solution which has been prepared separately:

Silver nitrate	30 gr.	.48	gm.
Potassium bromide	30 gr.	.48	gm.
Water	1 oz.	7.8	cc.

The prints are first immersed in the first bath for six or seven minutes, according to the warmth of tone required, then rinsed and immersed in the second bath until toning is complete. The longer prints are left in the first bath the colder is the final tone. Accordingly by regulating the time of immersion in this bath the tones may be regulated to meet the desires of the operator, so that the action of the bath is completely under control.

The first solution is used at a lukewarm temperature; the second at the normal temperature of the ordinary hypo-alum bath.[3]

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[3] *Abel's Photographic Weekly*, 1921, p. 224; *Brit. J. Phot.*, 1921, **68**, 680.

Sulphur Toning with Acid Hypo.—When an acid is added to a solution of hypo, the latter is at once decomposed, one of the products being finely divided sulphur. A number of toning processes based upon the decomposition of hypo by an acid have been brought forward although none have come into extensive use. Processes of this nature were brought forward by Lumière and Seyewetz and H. Soar in 1914, by G. S. Hoell in 1915 and by the Eastman Research Laboratory in 1922.[4] In the method advised by the latter the prints are first immersed in a 5 per cent solution of sulphuric acid for ten minutes, then, after a brief rinse, in a 20 per cent solution of hypo saturated with borax.

Toning with the Polysulphides.—A cheap and simple method of sulphur toning and one which produces acceptable results on many emulsions consists in the use of a polysulphide, usually in the form of the inexpensive "liver of sulphur," a mixture of potassium polysulphide and potassium sulphate which usually contains certain impurities in the form of potassium carbonate and potassium thiosulphate.

The following formula is recommended:

"Liver of sulphur"	¼ oz.	12.5 gm.
Hypo	½ oz.	25 gm.
Water	20 oz.	1000 cc.

As the temperature of the toning bath must be about 80 to 90° F. (27–32° C.) and since the "liver of sulphur" itself has a softening action on gelatine it is well to harden the prints before toning in a solution of chrome alum, unless an acid fixing bath containing alum has been used in which case the degree of hardening will probably be sufficient. As the toning solution itself contains hypo, only a brief washing is required before toning. Toning requires from ten to fifteen minutes at the above temperature during which time but little outward change in the color of the print will be observed. As the subsequent washing proceeds, however, and the yellow discoloration disappears the final color of the print becomes apparent. Blue spots arise from the presence of iron, due either to the use of trays in which iron is exposed or to the use of impure "liver of sulphur." The remedy is, in either case, obvious.

E. Underberg advises the use of ammonium polysulphide which he prepares as follows:[5] A stock solution is prepared by dissolving pure sulphur in commercial ammonium sulphide until the point of saturation is reached and then decanting the clear solution which keeps well. For toning, from ten to fifteen drops (.3–.6 cc.) of this solution are added to ten ounces of water (284 cc.) which is heated to a temperature of 85 to 95° F. (30–35° C.). Toning proceeds rapidly and is complete within 5–10 minutes. Underberg considers this method one of the best because of its simplicity and regularity, the warm tones produced, and because the action is progressive, so that the action can be stopped at any time, in this way securing an intermediate tone due to the admixture of the original black with the toned image.

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[4] *Brit. J. Phot. Almanac,* 1914, p. 66; *Phot. Era,* March 1915, p. 127; *Brit. J. Phot.,* 1922, **69**, 73.

Lumière and Seyewetz, who investigated the use of "liver of sulphur" as a toning agent very thoroughly,[6] are of the opinion that the action of liver of sulphur on the developed image is comparable to colloidal sulphur and that the course of the reaction is as follows:

$$S + H_2O = H_2S + O,$$

$$Ag_2 + O = Ag_2O,$$

$$Ag_2O + H_2S = Ag_2S + H_2O.$$

As the actual toning agent in the above case is the polysulphide contained in the liver of sulphur it is plain that this might be used alone. The solution of potassium polysulphide may be prepared by the method described by Bullock.[7]

Dissolve one hundred grams of potassium hydroxide in water and make up the solution to a total of 1000 cc. (in English measures 1 ounce to a total volume of 10 fluid ounces). Saturate one half this solution with hydrogen sulphide and mix with the remainder. To this solution, which is substantially one of potassium sulphide, add 120 grams (1.2 ounces) of pure sulphur in powder, heat to the boiling point and boil for five minutes stirring rapidly all the time. The potassium pentasulphide solution thus formed is then allowed to cool, filtered and kept in a rubber-stoppered bottle tightly closed.

For use take 950 parts of water, 50 parts of the potassium pentasulphide stock solution and 2.5 parts of a 20 per cent solution of ammonium sulphide. This bath as prepared will remain clear for about an hour after which the sulphur may begin to separate out.

[5] *Brit. J. Phot.*, 1924, 71, 50.

[6] *Brit. J. Phot.*, 1923, 70, 733.

[7] *Brit. J. Phot.*, 1921, **68**, 451.

The time of toning is from 15–25 minutes at ordinary temperatures but the action may be greatly accelerated by the addition of either potassium sulphocyanide or potassium selenocyanide. With the addition of 2 per cent of sulphocyanide the rate of toning is approximately doubled. Increasing the amount of sulphocyanide increases the rapidity of toning but leads to a more purplish tone, which, however, may, in some cases, be an advantage.

Single Solution Sulphide Toning Processes.—A process of sulphur toning in which a solution of sodium sulphide containing an oxidizing agent together with some body to take up the caustic soda formed was described by Milton B. Punnett[8] in 1908, and similar processes were described by Dr. F. Kropf[9] in 1910, by E. Blake-Smith[10] in 1911, and in a leading article in the *British Journal of Photography* the previous year, while Dr. W. Triepel[11] patented under British Patent No. 24,378 of 1910 a process of like character.

The most successful of such methods, however, is that introduced by Mr. W. B. Shaw in 1923 in which the rôle of the oxidizing agent is filled by nitro aromatic derivatives, such as, for example, nitro-benzene, sodium meta-nitro-benzene sulphonate and sodium 4-nitro-toluene 2-sulphonate. The toning solution is compounded from two stock solutions as follows:[12]

Saturated solution of barium sulphide	15 parts
10 per cent solution sodium meta-nitro-benzene sulphonate	1 part

Both solutions keep well if stored in tightly corked bottles. A fungoid growth, however, will form in the nitro-benzene solution with time. This growth may be prevented by adding to the solution a small piece of thymol.

Prints immersed in this solution tone to a good sepia or brown within three to five minutes at a temperature of 60° F. (16° C.). The tones vary considerably with the emulsion; the greatest variation being observed with papers of the gaslight type. With bromide papers there is comparatively little variation in tone with different emulsions. The tones resemble very closely those obtained by other methods of sulphur toning and since the method is one which works rapidly, is simple in composition, produces agreeable tones and does not require the application of heat it will undoubtedly develop into one of the most popular methods of sulphur toning.

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[8] *Brit. J. Phot. Almanac*, 1908, p. 653; *Brit. J. Phot.*, 1910, **57**, 869.

[9] *Phot. Rund.*, 1910, **21**, 245; *Brit. J. Phot.*, 1910, **57**, 836.

[10] *Brit. J. Phot.*, 1911, **58**, 140.

[11] 1910, **57**, 835.

[12] *Brit. J. Phot.*, 1923, **70**, 759.

The Indirect Process of Sulphide Toning.—Of the many methods of producing sepia and warm-brown tones, the indirect process is one of the most reliable and is perhaps in wider use than any other method. The well-washed prints are first bleached in one of a number of baths, the most prominent example of which consists of potassium ferricyanide and bromide, briefly washed and toned in a solution of sodium, ammonium or barium sulphide. As the latter has a softening action on gelatine the use of an acid fixing and hardening bath is advisable particularly in summer or when high temperatures cannot be avoided.

For bleaching the print any of the following mixtures may be used:

A. Ferricyanide-bromide (*B. J. Almanac Formula*)

Ammonium bromide	100 gr.	10.41 gm.
Potassium ferricyanide	300 gr.	31.23 gm.
Water to make	20 oz.	1000 cc.

B. Permanganate (*T. H. Greenall*)

(*a*)	Hydrochloric acid (31.8 per cent)	3 oz.	150 cc.
	Water to make	20 oz.	1000 cc.
(*b*)	Potassium permanganate	40 gr.	4.5 gm.
	Water	20 oz.	1000 cc.

For use take one part each of (*a*) and (*b*) to 6 of water. Both *a* and *b* keep well in tightly corked bottles. This bleacher has the advantage that any traces of hypo left in the print are destroyed. With the ferricyanide-bromide bleach the presence of hypo leads to reduction of the print since the two interact to form the well-known Farmer's reducer. The stain which results from the use of permanganate is usually removed in the sulphide bath, however, should it remain after sulphiding, the print is immersed in

Oxalic acid	½ oz.	9.1 cc.
Water	50 oz.	1000 cc.
Sodium sulphite	1 oz.	18.2 gm.

until removed.

The following phosphate-ferricyanide bleacher is recommended by Mr. T. H Greenall as giving colder tones than the usual ferricyanide-bromide mixture. It may therefore be of value where a particular emulsion tends to produce an undesirable warmth of tone.[13]

Sodium phosphate	200 gr.	104 gm.
Potassium ferricyanide	40 gr.	21 gm.
Water	4 oz.	1000 cc.

Numerous other methods of bleaching have been advised from time to time by various workers. It is doubtful, however, if there is any real advantage in their use as compared with the usual ferricyanide-bromide mixture for, as has been shown by Bullock in an admirable paper on the subject of sulphide toning by the indirect process, the composition of the bleacher has comparatively little effect on the resulting tone.[14]

When the bleaching action is complete and it is seen that no further action takes place, the prints are removed and washed either in running water or in successive changes until the yellow discoloration is removed. The length of this washing has no great influence on the final tone if within reasonable limits, but too long a washing is to be avoided while it is equally important that washing be sufficient to entirely remove every trace of the stain from the ferricyanide. When washed the prints are ready for sulphiding.

However, if at this point the prints are immersed for about ten to fifteen seconds in a 1 per cent solution of sodium carbonate, then rinsed in water and sulphided, a much cooler tone is obtained. This mode of procedure, indicated first by Bullock,[15] is especially advantageous for some emulsions which tend to produce extremely warm tones.

The conversion of the bleached image into a colloidal silver sulphide can be accomplished by a number of substances, the more important of which are sodium, ammonium and barium sulphide. On account of its lower cost, sodium sulphide is generally used. Ammonium sulphide is claimed by some to give richer tones but the author has never been able to find much difference in this respect provided both substances are pure and other conditions are alike in both cases.

Sodium sulphide does not keep at all well in solution and for the best results it is advisable to make up a fresh solution at the time of use. This may conveniently be a 1 per cent solution.

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[13] *Brit. J. Phot.*, 1912, **59**, 91.

[14] *Brit. J. Phot.*, 1921, **68**, 447.

[15] *Brit. J. Phot.*, 1921, **68**, 447.

Sodium sulphide	48 gr.	10 gm.
Water	10 oz.	1000 cc.

There is no advantage in the use of a solution stronger than 1 per cent and there is the danger of blisters to be considered with solutions much above this strength. Above a concentration of 1 per cent the tone is not appreciably affected by the strength of the sulphide bath; below this point, however, the tone is yellowish and lacking in vigor, the results approaching the normal as the concentration of the sulphide solution reaches one per cent.

While in general the use of stock solutions of sodium sulphide cannot be strongly recommended (partially decomposed sulphide from such solutions being one of the most frequent sources of failure in indirect toning), relatively strong solutions of sulphide, if carefully made with distilled or boiled water and kept in tightly corked bottles using rubber stoppers, will keep for two or three weeks. Weak solutions do not keep well and it is advisable to make a fairly strong solution which has to be diluted considerably with water immediately before use.

The use of barium sulphide was advised by Namias in 1911. It has the advantage of keeping better in solution than either the sodium or ammonium salt; of being partially free from the objectional odor of the latter and producing colder tones. Its effectiveness, however, varies considerably with different emulsions, some of which refuse to tone. The salt is only sparingly soluble in water and a saturated solution forms about the most convenient strength for general use. This is made as follows:

Barium sulphide	½ oz.	12.5 gm.
Water	40 oz.	1000 cc.

The principal objection to the use of barium sulphide, aside from its unsatisfactory performance with some emulsions, is the precipitation of an insoluble barium compound on the face of the prints. This may usually be removed by rubbing briskly with a wad of wet absorbent cotton and may be entirely prevented by the addition of a very small quantity of sodium sulphate to the stock solution of barium sulphide.

The use of the sulphydrate was advised by Douglas Carnegie[16] in 1907, on account of its better keeping properties and freedom from objectional odor. It has never been extensively used for this purpose, however.

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[16] *Brit. J. Phot. Almanac*, 1907, p. 676.

Re-bleaching of Sulphide-Toned Prints.—Prints toned by the indirect process may be re-bleached and developed should the color of the toned print be unsatisfactory. For this purpose the following bleacher is recommended:

A. Hydrochloric acid	10 per cent solution	
B. Potassium permanganate	5 per cent solution	
For use take *A*	1 oz.	250 cc.
B	30 min.	15.5 cc.

After bleaching the stain from the manganese is removed by the use of oxalic acid or sodium bisulphite, as previously described, and the print can then be developed in any ordinary developer or toned to a darker sepia by re-sulphiding.

Indirect Sulphide Toning with Intermediate Redevelopment.—Practically the only control which the worker has over the color of the toned image in the case of sulphide toning as previously described is in the production of the original print. There is a means, however, of rendering the process more responsive to the desires of the worker. This means consists in partial redevelopment of the bleached image by means of a weak developer immediately before sulphiding. The intermediate redevelopment combined with sulphiding has the effect of producing an image consisting partly of metallic silver (the redeveloped image) and of silver sulphide; the relation between the two images determining the tone of the print.

For this manner of working the prints are bleached and washed in the ordinary way, then immersed in the regular print developer which has been diluted with from 10–15 parts of water and containing no bromide. The use of a weak developer causes the image to develop slowly and gradually so that its action can be easily followed. The extent to which this intermediate redevelopment is carried determines the final tone; the longer the period of development the stronger is the black silver image and the colder the tone of the final result. When dealing with batches of prints the use of a short stop bath to arrest the action of the developer is necessary as its action grows more rapid towards the end. This stop bath may be the regular acetic acid bath as recommended on page 377 of the chapter on Printing on Developing Papers.

After having been rinsed in the short stop bath, the prints are washed for several minutes in running water or in several changes of water and then transferred to the sulphide bath in which toning is completed. They are finally washed thoroughly in water and dried as usual.

For successful working of this method careful attention to the following points is essential:

1. The operations of bleaching and redevelopment must be conducted in artificial light *not daylight.*

2. To obtain a uniform tone on all prints from the same negative the intermediate development must be alike for all. As the developing solution is a weak one, care must be taken not to overwork it. In fact, it is best to take a small quantity of fresh solution for each print.

When one has become accustomed to the appearance of the print in the developer and the effect of the extent of redevelopment on the final tone, this method of working becomes quite easy and certain while its latitude has obvious advantages.[17]

Mercury-Sulphide Toning (Bennett's Method).—In another process of sulphide toning introduced by Mr. H. W. Bennett the tone of the print is controlled by the addition of mercuric chloride to the bleaching solution. The addition of mercuric chloride to the usual ferricyanide-bromide bleaching solution results in an image which consists partly of a compound of mercury and partly of silver sulphide; the tone depending upon the relative proportions of the two compounds.

The following are the revised formulas given by Mr. Bennett in 1921.[18]

A.	Potassium ferricyanide	1	oz.	100	gm.
	Potassium bromide	1½	oz.	150	gm.
	Water to make	9	oz.	1000	cc.
B.	Mercuric chloride	60	gr.	12.5	gm.
	Potassium bromide	60	gr.	12.5	gm.
	Water to make	5	oz.	500	cc.
C.	Sodium sulphide	1	oz.	100	gm.
	Water to make	9	oz.	1000	cc.

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[17] A method of combined development and sulphiding in a single solution has been described by Mr. T. H. Greenall (*Phot.*, 1912, p. 91; *Brit. J. Phot. Almanac*, 1913, p. 659), but has no advantages and some disadvantages over the method described.

[18] *Brit. J. Phot.*, 1921, **68**, 25.

The use of mercuric chloride has the effect of producing a certain amount of intensification which may be compensated for by reducing the amount of exposure or the time of development of the original print so as to produce lighter prints which will, when toned, be of the proper strength.

The following table shows the composition of the bleaching solution for various tones and the relative exposures required for the original prints designed for toning:

Color	*A*	*B*	Water	Rel. Exposure
Normal sepia	40 parts	— parts	480 parts	10 seconds
Cool sepia	40 "	20 "	480 "	9 "
Colder sepia	30 "	30 "	480 "	8 "
Brown-black	30 "	50 "	480 "	7 "
Engraving black	30 "	90 "	480 "	6 "

After having been bleached in a bleacher compounded as directed for the tone desired, the prints are washed briefly and passed through three successive baths of 1 per cent hydrochloric acid after which they are again washed and finally sulphided as usual.

The engraving black tone, it may be mentioned, is not the cold neutral black of the ordinary developed print but is a purer, richer black, resembling very closely the tone of an etching or engraving. It has been the experience of the writer that the best results are secured on bromide papers and that these vary considerably in adaptability to the process.

Toning with Copper.—Dr. J. M. Eder[19] in conjunction with V. Toth claims to have been the first to show that silver prints could be toned to a reddish tint by treatment with cupric ferricyanide. Later Namias showed that copper salts mixed with potassium ferricyanide deposited cuprous ferrocyanide on silver prints.[20] Eder on returning to the subject in 1900 advised the use of cupric sulphate, ammonium carbonate and potassium ferricyanide.[21] The same year Mr. W. B. Ferguson, as the result of a long series of experiments, advised the use of cupric sulphate, potassium ferricyanide and a neutral citrate such as potassium citrate which he found far superior to ammonia or ammonium carbonate which had been advised by Namias and Eder.[22]

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[19] Eder, *Phot. Korr.*, 1876.

[20] Namias, *Phot. Korr.*, 1894, 327.

[21] *Phot. Korr.*, 1900, 36, 537.

[22] *Phot. J.*, 1900, 25, 133.

Two solutions are required as follows:

(British Journal Formula)

A. Cupric sulphate	60 gr.	6.25 gm.
Potassium citrate (neutral)	240 gr.	25 gm.
Water to make	20 oz.	1000 cc.
B. Potassium ferricyanide	50 gr.	5.2 gm.
Potassium citrate	240 gr.	25 gm.
Water to make	20 oz.	1000 cc.

For use take equal parts. Should the prints appear purplish in the highlights increase the amount of potassium citrate in either *A* or *B*.

The range of colors obtainable with copper toning extend from warm-black through varying shades of brown on to red chalk, the action being progressive so that the various tones follow one another in a definite order as the action proceeds. There is no intensification as with uranium and the results are quite permanent.

According to Namias the tone is much improved if the prints after toning are immersed in the following bath for fifteen minutes:

Cupric sulphate	154 gr.	20 gm.
Ammonium chloride	355 gr.	50 gm.
Hydrochloric acid	77 min.	10 cc.
Water to make	16 oz.	1000 cc.

This bath may be used repeatedly and keeps quite well. As some silver chloride is formed, refixing is necessary, but since an acid bath would have a reducing action on the image a plain hypo bath with a concentration of about 5 per cent should be used.

Namias has lately recommended another method of copper toning.[23] In this the prints are first bleached in

Copper sulphate	614 gr.	80 gm.
Neutral sodium citrate	81 gr.	10.5 gm.
Potassium ferricyanide	16 oz.	1000 cc.
Water to make	73 gr.	9.5 gm.

After bleaching the prints are washed well and redeveloped in a metol-hydrochinon developer containing 0.2 per cent potassium bromide. If development is carried out in daylight the silver ferrocyanide is reduced while the copper ferrocyanide is unaffected. As the process has some intensifying action the prints should be somewhat lighter than actually required.

Toning with Uranium.—The range of tones obtainable by toning with uranium extends from warm-black, through various shades of brown to plum colors and various shades of red, terminating in a bright brick-red. The toning action is progressive, the various colors appearing in a definite order as the action is allowed to proceed. Owing to its intensifying action, uranium toning is not a process for dark, fully developed prints and prints which are to be toned with uranium should be made somewhat lighter than is required of the finished result.

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[23] *Il. Prog. Fot.*, 1915, p. 347; *Bull. Soc. franc. Phot.*, 1922, **64**, 26.

As regards the permanency of prints toned with uranium there is some question. While in many cases the results are reasonably permanent, except for a slight metallic luster which forms around the edges, in other cases the toned image does not appear at all stable. While much is no doubt due to improper manipulation during and after toning, when all is said and done, prints toned with uranium cannot be said to be very reliable.

There are numerous methods of toning with uranium. We give Sedlaczek's method, which, if not the best, is one of the best, having behind it the experience of a man who has devoted much time to the subject.

As a result of theoretical reasoning and considerable research, Dr. Sedlaczek recommends the following formula:[24]

Uranyl nitrate	38 gr.	5 gm.
Potassium citrate	38 gr.	5 gm.
Potassium ferricyanide	15 gr.	2 gm.
Ammonia alum	77 gr.	10 gm.
Pure hydrochloric acid	2 min.	0.3 cc.
Water	16 oz.	1000 cc.

It is a matter of considerable importance that the print be thoroughly washed as the uranium bath is decomposed by hypo, producing stains which cannot be removed.

A print immersed in the above solution shows virtually no change in the first half-minute, after which a slight brownish coloration becomes apparent which finally deepens into a reddish-brown. The colors produced with a bath of the above composition are far superior to those produced by the older methods, being darker and richer owing to the presence of some of the black silver image.

The removal of the yellowish coloration after toning is greatly facilitated by the use of the following bath:

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[24] *Phot. Ind.*, 1924, p. 234; *Amer. Phot.*, 1925, p. 8.

Potassium citrate	38 gr.	5 gm.
Sodium sulphate (*not sulphite*)	192 gr.	25 gm.
Water	16 oz.	1000 cc.

Three or four such baths may be required to remove the yellowish coloration entirely. The print should then be washed in running water free from alkalis for a minute or so, then fixed for five minutes in a 0.5 per cent solution of hypo followed by washing in running water made acid by the addition of 0.1 per cent of glacial acetic acid.

The impermanence of uranium-toned prints, of which so much is heard, is due, according to Dr. Sedlaczek, to the omission of after fixing, or to the omission of treatment with hydrogen sulphide. Uranium-toned prints thus treated may be considered reasonably permanent. For this latter treatment either of the following sulphiding baths may be employed:

Sodium sulphide	19 gr.	2.5 gm.
Hydrochloric acid	8 min.	1 cc.
Water	16 oz.	1000 cc.

or

Barium sulphide	77 gr.	10 gm.
Hydrochloric acid	23 min.	3 cc.
Water	16 oz.	1000 cc.

Combining the fixing bath with cobalt produces colder tones tending to violet as the amount of cobalt is increased. For this purpose the following formula may be suggested as a beginning:

Hypo	35 gr.	5 gm.
Potassium citrate	8 gr.	1 gm.
Cobalt nitrate	8 gr.	1 gm.
Water	16 oz.	1000 cc.

Iron Toning Processes.—The use of toning processes employing salts of iron is rather limited, being confined principally to blue toning, although by combination with uranium or by sulphiding green tones may be obtained.

For a blue toner the following formula is recommended:

(*B. J. Almanac Formula*)

Ferric ammonium citrate (10 per cent solution)	2 oz.	10 cc.
Potassium ferricyanide (10 per cent solution)	2 oz.	10 cc.
Acetic acid (10 per cent solution)	20 oz.	100 cc.

The well-washed prints are immersed in this solution until the required tone is reached, then washed in running water until the whites are clear.

Green tones may be obtained by toning with iron and sulphiding. The green tone is due to the combination of the blue image (produced by toning with iron) and the yellow silver sulphide produced by sulphiding. Three stock solutions are required:

A.	Potassium ferricyanide	5 gm.	84 gr.
	Ammonia	5 drops	
	Water to make	100 cc.	3½ oz.
B.	Ferric ammonium citrate	2 gm.	33 gr.
	Hydrochloric acid (conc.)	5 cc.	80 min.
	Water to make	100 cc.	3½ oz.
C.	Sodium sulphide	1 gm.	15 gr.
	Water	100 cc.	3½ oz.
	Hydrochloric acid (conc.)	5 cc.	80 min.

The well-washed print is placed in *A* until completely bleached, then washed free from stain, placed in *B* for four or five minutes, rinsed two or three times in plain cold water and finally transferred to *C* for 5 minutes. A short washing in running water completes the process. The purity of the whites of the print depends upon the washing following the bleacher and it is therefore necessary that this operation be thorough and complete. The pale blue of the highlights which is so observable on the wet print generally disappears on drying.

Toning with Vanadium.—Apparently the first description of vanadium as a toner was made by Prof. R. Namias in 1901.[25] The method adopted by him was to immerse the print in a solution of a ferricyanide and then into a solution containing a vanadium salt. The normal color of the silver image toned with vanadium is yellow and in 1903 Namias introduced the following formula for obtaining green tones—the green tone being due to the presence of a blue ferriferrocyanide image and the yellow vanadium ferrocyanide: [26]

Ferric chloride	4.8 gm.	23 gr.
Vanadium chloride	4 gm.	19 gr.
Ammonium chloride	10 gm.	48 gr.
Hydrochloric acid (conc.)	10 cc.	48 min.
Water	1000 cc.	10 oz.

The objection to this, as well as all early methods of vanadium toning, is that the solutions used contain a chloride and hydrochloric acid so that there must be some silver chloride formed and this has the effect of reducing the transparency of the image and hence its brilliancy. Mr. E. J. Wall[27] has worked out and described a method in which this objection is overcome by the use of either the oxalate or sulphate of vanadium.

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[25] *Eder's Jahrbuch,* 1901, p. 171.

[26] *Eder's Jahrbuch,* 1903, p. 158.

Either of these salts can be made quite easily from ammonium metavanadate which is a comparatively inexpensive salt. To make the oxalate place 100 grams (3 oz. 230 grains) of ammonium metavanadate in a beaker or evaporating dish and add 460 grams pure oxalic acid. To this add 500 cc. (17 oz. 287 minims) distilled water stirring constantly all the while and then heat the mixture. As the temperature rises it forms at first a thick paste which becomes more fluid as the temperature rises while the color changes from white to orange-red and finally to a dirty gray-green. More water may be added and heating continued until a perfect solution is obtained. The color will then change to a brilliant blue and the total bulk of the solution can be made up to 1477 cc. (52 oz.) when we have a 20 per cent solution of vanadium oxalate containing a slight excess of oxalic acid.

The actual toning solution is compounded as follows:

Vanadium oxalate solution (20 per cent)...	50 cc.	½ fl. oz.
Oxalic acid (saturated solution)...........	50 cc.	½ fl. oz.
Ammonia alum (saturated solution).......	50 cc.	½ fl. oz.
Ferric oxalate solution....................	*quant. suff.*	
Glycerine	50 cc.	½ fl. oz.
Potassium ferricyanide (10 per cent solution)	10 cc.	48 min.
Water	1000 cc.	10 oz.

To prepare this solution add the oxalic acid to the vanadium and add half the water, then add the alum solution and then the ferric oxalate. The only means of determining the exact quantity of this is by trial. The more used the bluer the toned result. The ferricyanide should be mixed with the glycerine and the other half of the water, then added to the remainder of the solution. This will result in a bright, clear, green solution which will not precipitate while toning. As it is sensitive to light, however, it is best to use it by artificial light.

The alum is added for the purpose of keeping the highlights clear and the acid helps to keep the solution while in use. The glycerine is not absolutely necessary and may be omitted if desired but the bath is then more likely to produce a deposit.

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[27] *Phot. J. Amer.*, 1921, 57, 96; *B. J. Almanac*, 1922, p. 395.

Toning requires from ten to fifteen minutes, after which the prints are to be immersed in a 10 per cent solution of sodium sulphate for five minutes, washed briefly and dried. Fixing is unnecessary.

Minor Toning Processes.—There are a number of minor processes of chemical toning of limited application owing to the unsatisfactory character of the result or to the difficulty of securing consistent results. Recent investigations of some of these processes have shown that they are capable of considerable improvement and it appears quite likely that in the future some of them, at least, may be more widely employed than at the present time. This is particularly true of toning processes involving the use of stannous and cobaltic compounds. In both of these fields considerable development has taken place in recent years, largely as a result of the work of Formstecher and of Druce in the case of the processes with stannous salts and of P. Strauss with cobalt processes. The reader is referred to the published papers of these workers (a list of which will be found in the bibliography following this chapter) for further information on these processes.

There has likewise been a renewal of interest in processes of selenium toning and a number of patents have been taken out, and several papers published on toning processes involving the use of selenium. It has not as yet, however, come into general use, except in a limited way with certain products for which it has proved especially suitable. The same is true of several processes employing hydrosulphite as worked out by A. Steigmann and for colloidal silver processes described by Lumière and Seyewetz, Rawling, Formstecher, Shelberg and others.

In a work on the toning of photographic images these minor processes would of necessity assume considerable importance. In a general work, such as this, lack of space prevents a lengthy treatment of such processes as are not in general use.

Books

Blake-Smith—Toning Bromides and Lantern Slides, 1904.
Fraprie—How to Make Prints in Colors.
Mebes—Der Bromsilber und Gaslicht Papier Druck, 1913.
Sedlaczek—Die Tonungsverfahren von Entwicklungspapieren, 1906.
Stenger—Die Kopierverfahren, 1926.

CHAPTER XXI

PRINTING WITH SALTS OF IRON AND PLATINUM

The Platinotype Process

Introduction.—Platinum is one of the most stable of metals. It is affected very little by the strongest alkalis and not at all by sulphuric, hydrochloric or nitric acids nor any substance found in the atmosphere. It follows, therefore, that prints, the image of which consists of pure metallic platinum, are as stable as the paper on which they are made. Not only are platinum prints permanent but they also have a certain intrinsic quality that is not possessed by any other process. Perhaps no printing process can reproduce all the original gradations of a good negative so faithfully, while many shades of sepia, warm and engraving black of unsurpassed purity may be easily obtained. Platinotype is also one of the simplest processes to manipulate.

The sensitiveness of certain salts of platinum to light was observed by Sir John Herschel in 1832 and by Hunt in 1844, but the development of the process is due to W. Willis, an Englishman, who took out a patent for the first practical method in 1873; a second followed in 1878, and a third in 1880. The work of two Austrian investigators, Pizzighelli and Hubl, also deserves mention more particularly for their work on the direct printing-out method. Their little book[1] is a complete treatise on the subject and despite its age is still one of the best textbooks on the process.

The Theory of the Process.—Although platinum salts in the platinous state are sensitive to light, particularly in the presence of organic matter, the present platinotype process is an indirect one depending upon the reduction of a ferric salt to the ferrous state upon exposure to light and on the fact that this latter when dissolved in a solution of potassium oxalate is capable of reducing a platinum salt to the metallic state.

Paper is coated with potassium chloroplatinite (K_2PtCl_4) and ferric oxalate ($Fe_2(C_2O_4)_3$) and dried. On exposure to light the ferric salt is reduced to the ferrous state in proportion to the amount of light action and upon immersion in potassium oxalate solution the ferrous salt is dissolved and the platinum salt with which it is in contact is reduced to the metallic state. Berkeley's formula, which is generally accepted, is as follows:

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[1] *Platinotype,* translated by Abney—published by Harrisons, London, at 2 shillings. (Now out of print.)

$$\underset{\text{Ferrous oxalate}}{6Fe(C_2O_4)} + \underset{\text{Potassium chloroplatinite}}{3PtK_2Cl_4} \rightarrow \underset{\text{Ferric oxalate}}{2Fe_2(C_2O_4)_3} + \underset{\text{Ferric chloride}}{2(FeCl_3)} + \underset{\text{Potassium (Platinum chloride)}}{6KCl + 3P}$$

The remaining salts are dissolved in baths of dilute hydrochloric acid, leaving an image consisting of metallic platinum.

Commercial Papers and their Treatment.—Platinum paper is supplied in a wide variety of surfaces and in black and sepia. The paper is extremely sensitive to moisture and therefore it is sent out in sealed metal cans which contain a small quantity of a moisture-absorbing salt so as to keep the paper dry and in good condition. The can should not be opened before the paper is to be used and then only in a dry place. When opened the can should not be allowed to lay around open in the workroom but the paper which is needed for immediate use should be removed and the remainder again placed in the can and the latter sealed. If it is necessary to remove a few sheets at irregular intervals, it is advisable to insert a freshly dried piece of calcium chloride each time in order to take up any moisture which the paper might have absorbed while the can was open. Too much care cannot be taken in keeping the paper dry, for if kept dry it will remain in good condition almost indefinitely, while if allowed to absorb moisture from the atmosphere, it will spoil very quickly and yield flat and lifeless prints.

For best results the negative should have a little more contrast than is necessary for soft gaslight paper although the contrast can, to a certain extent, be controlled in development. For a full scale print the extreme shadows of the negative should be free from fog and the highlights plucky yet not blocked up. A little experience will quickly show the proper kind of negative. Thin, under exposed negatives are not suitable as the process reproduces all the faults as well as all the beauties of a negative. For some reason, a moderately thin negative is better than a dense one and care should, therefore, be taken when making the negative not to overtime.

Exposure.—The paper is very sensitive to light and should be handled only in artificial or exceedingly subdued daylight as it is from three to four times as fast as the silver print-out papers which we have been considering. Very bright daylight should not be allowed to reach the paper nor should it be exposed to the direct rays of a strong artificial light for any length of time.

The negative, which should be thoroughly dry, is placed in the frame with the emulsion side up and the paper placed with its sensitive side in contact with the negative in the same manner as has been described in connection with other print-out papers. One essential difference, however, consists in the use of a sheet of waxed paper or vulcanized rubber over the paper to prevent the access of moisture from the atmosphere while exposing. This is especially important on damp or dull days when the exposure is prolonged but is always to be advised. The progress of printing is examined in exactly the same way as with gelatine P-O-P, greater caution, however, being taken not to expose the paper to strong light while the examination is being made. It is rather difficult to describe the appearance of the paper when the exposure has been sufficient but the precise moment at which the exposure should terminate is easily gained with a little experience. For the beginner the best guide that the author can give is the following: *When the image is fully seen in brownish gray against the yellow surface of the paper and full detail can be seen in the shadows the exposure is sufficient.* In the majority of cases, however, especially with papers that are old or those that are home-made, a test should be made. Over exposure will, of course, give a dark print while under exposure will give a light print lacking detail in the highlights.

Development.—The chemicals necessary for developing may be obtained from the American agents Willis and Clements of Philadelphia in ½ lb. packages or the following formula may be used for all grades of black papers:

Potassium oxalate	5 oz.	33.4 gm.
Hot water	15 oz.	1000 cc.

Hot water is required in making up the solution but the developer should be allowed to cool before using. It keeps indefinitely and may be used over and over, sufficient fresh solution being added to it from time to time in order to keep up the required volume.

Since the image appears almost immediately, the paper must be immersed in the solution in such a manner that it is evenly and quickly covered in one sweep. Any air bubbles which appear should be carefully removed with a soft brush or the tip of a finger. With correct exposure, there is no fear of over development and after a full minute's immersion the print may be removed and immersed in a clearing bath composed of

Water	60 oz.	1000 cc.
Hydrochloric acid C.P.	1 oz.	16.6 cc.

After five minutes' immersion in this bath the print should be transferred to a second bath of similar composition for five minutes and then to a third for another five minutes after which it is washed for fifteen to twenty minutes in running water and dried. Prints dry better when hung by the corners on a line than when placed between blotters.

Variations in Contrast.—For softer prints one of the following modifications must be made:

a. Heat the developer and print slightly less. On no account, however, should the temperature of the developer exceed 180° F.
b. The addition of a small amount of hydrochloric acid, say 1 drop C.P. to each ounce of developer.
c. Old paper gives less contrast than fresh.
d. Some authorities recommend that printing be conducted under signal green glass but in the writer's experience the increase in contrast secured in this manner is almost insignificant.

For greater contrast:

a. The developer may be diluted and greater time allowed for its action. It should not, however, be diluted further than one part of the normal solution already given to 4 parts of water.
b. The addition of small quantities of potassium bichromate to the developer. The amount for a given negative can be determined only by experience, but only a small quantity is needed and the addition of three or four drops 10 per cent solution to each 16 of developer has a considerable effect. In no case should there be more than 1 grain to 10 ounces of developer used.
c. Diluting the developer with an equal part of glycerine and clearing in a strong acid bath.

When using the last named method the image requires to be somewhat darker than usual. Development is conducted in the usual manner but owing to the restraint exercised by the glycerine the action is slow and the shadows develop more rapidly than the highlights. As soon as the desired depth is reached, the print is removed from the developer and immersed in a strong acid bath to arrest further development. The bath for this purpose should be composed of

Water	30 oz.	1000 cc.
Hydrochloric acid C.P.	1 oz.	33·3 cc.

Owing to the difficulties of adjusting exposure and avoiding streaks in development, the use of potassium bichromate is preferable for the purpose of securing increased contrast. However, many workers employ the glycerine method in order to secure the peculiar velvet effect which it gives because the image is held upon the surface instead of sinking within the pores of the paper.

Variations in Color.—A special "sepia" paper is supplied by the Platinotype Company, but sepias and various shades of warm-black may be secured on the black papers by the addition of mercury to the developer.

In general the "sepia" paper is handled in the same manner as the "black" but the following points require separate mention. The paper is rather more sensitive to light than the black papers and, therefore, prints faster and requires to be protected from the light with greater care. The following developer is recommended:

Ordinary black developer	10 parts—20 oz.
Oxalic acid saturated solution	1 part — 2 oz.

or the special sepia developing salts sold by the Platinotype Company. For the best results, the developer should be used at a temperature of 150° to 160° F.; but very good results, particularly with certain negatives, may be secured in a cool developer.

Trays which are used for the development and clearing of sepia prints should be set aside for that purpose only and not used for black papers. Neither should the two papers be cleared in the same solution nor should they be washed together.

Very fine sepia tones may be secured on black paper by the addition of mercury. The use of mercury alone will degrade the highlights so glycerine must be added to retard its action. The following developer is advised by F. J. Mortimer:

A. Cold bath black developer	1 part—10 oz.
Glycerine	1 part—10 oz.
B. 10 per cent solution of mercuric chloride in alcohol.	

For use, *A* and *B* are mixed according to the tone desired—the larger the proportion of *B* the warmer the color.

The following proportions are suggested:

A 40 parts, *B* 1 part (*a*)
A 30 parts, *B* 1 part (*b*)
A 20 parts, *B* 1 part (*c*)
A 20 parts, *B* 2 parts (*d*)
A 20 parts, *B* 3 parts (*e*)
A 20 parts, *B* 4 parts (*f*)

(*a*) gives a warm-black; (*b*) brown-black; and (*f*) a warm-sepia; this last is the maximum amount of *B* which it is permissible to use. For a given depth of printing (*a*), (*b*), and (*c*) give darker prints while (*d*), (*e*), and (*f*) give lighter prints, so it is necessary that an allowance be made in printing in order to secure prints of the desired depth.

Another formula due to C. F. Inston is as follows:

A.	Potassium oxalate	2 oz.	130 gm.
	Water	14 oz.	1000 cc.
B.	Potassium citrate	150 gr.	21 gm.
	Citric acid	240 gr.	35.7 gm.
	Mercuric chloride	90 gr.	13.4 gm.
	Water	14 oz.	1000 cc.

For use take equal parts of *A* and *B* and use at a temperature of about 100° F.

Mercury-toned prints should be cleared in a bath of about one third to one fourth the usual strength, say:

Water	200 oz.	1000 cc.
Hydrochloric acid C.P.	1 oz.	5 cc.

Care should be taken not to overwork this weak acid bath or the prints will not be permanent.

Silver-Platinum Papers.—Owing to the very high price of platinum in 1913, the Platinotype Company introduced a silver-platinum paper under the trade name Satista. The prints on this paper are excellent and practically indistinguishable from true platinotypes. They are luminous and full of atmosphere and the shadows rich and transparent. Moreover, the prints are reasonably permanent and the manipulation of the paper is very simple. The paper is very sensitive to moisture and must be kept in airtight tubes like platinotype. Exposure is conducted in the same manner as platinotype but as the paper is faster, only about one fourth of the time is required in printing. The developing solution consists of oxalic acid and potassium oxalate, with the addition of a small amount of ammonium chloride in the case of weak negatives to increase the contrast. After development, prints are cleared in a solution of binoxalate of potassium, washed for eight minutes in running water, fixed in a bath of sodium thiosulphate (" hypo ") and finally washed for thirty minutes in running water to eliminate all traces of the latter salt. The cost of the paper is about one third of platinotype and full supplies may be obtained from the agents, Willis and Clements, Philadelphia, Pa.

Formulas for the preparation of similar papers have been published by Thomson.[2] The following is the sensitizer advised:

Ferric oxalate	20 gr.	41.6 gm.
Iron and ammonium citrate (green)	20 gr.	41.6 gm.
Potassium oxalate	20 gr.	41.6 gm.
Platinum solution	10 min.	20.8 cc.
Potassium bichromate solution	from 3–10 min.	5.5–20.8 cc.
Gum arabic	10 gr.	20.8 gm.
Distilled water	1 oz.	1000 cc.

Mix in above order and allow to stand for twenty-four hours.

The platinum solution named in the above formula is as follows:

Potassium chloroplatinite	15 gr.	15.6 gm.
Phosphoric acid	2 dr.	150 cc.
Distilled water	1 oz.	500 cc.

When dissolved add water to make a total of two ounces (1000 cc.).

The paper may be sensitized either by floating or by brush and is dried in a moderately warm room. When dry, it is ready for exposure which is conducted in the same manner as platinotype.

The stock developing solution consists of:

Distilled water	1 oz.	1000 cc.
Silver nitrate	40 gr.	83.3 gm.
Citric acid	10 gr.	21 gm.
Oxalic acid	10 gr.	21 gm.

Filter and use clear solution, diluting for use with seven parts of water. To secure pure black tones, the ferric oxalate must be absolutely fresh. If the image lacks strength, use a strong developer. Prints blacken immediately and after development are removed to a bath of hypo, 10 grains in six ounces of water (3.5 gm. to 1000 cc.), for ten minutes. Contrast may be regulated by the proportion of potassium bichromate (5 per cent solution), using from one to ten drops to each ounce of sensitizer (2–20 cc. to each 1000 cc.) according to the degree of contrast desired.

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[2] *American Photography*, 1915, Nov., p. 632.

The Kallitype Process.—Kallitype was the name given by W. W. Nicol to a ferric printing process in which ferric salts are reduced by exposure to light to the ferrous state and in this condition are able to convert a silver salt into the metallic state. The process is, therefore, similar to platinum excepting in the use of silver in place of platinum.

Suitable paper is sized in a solution of arrowroot:

Bermuda arrowroot	90 gr.	18.7 gm.
Water	10 oz.	1000 cc.

Using a little of the water make a thin cream of the arrowroot. Then heat the remainder of the water to the boiling point and add to the arrowroot mixture. As the solution does not keep it must be made up fresh for each batch of paper sized. The sizing solution is best applied with a Blanchard brush.

When dry the paper is sensitized with:

Ferric oxalate	75 gr.	15.6 gm.
Oxalic acid	5 gr.	1 gm.
Silver nitrate	30 gr.	6.25 gm.
Distilled water	1 oz.	100 cc.

The ferric oxalate must be dissolved with the oxalic acid in warm water, then filtered and the silver nitrate added.

The operations of sensitizing, drying, and exposing are as with platinotype.

Both black and sepia tones may be had, depending on the developer used. For black tones the following is recommended:

Borax	1 oz.	91 gm.
Rochelle salt (sodium-potassium-tartrate)	¾ oz.	68.3 gm.
Distilled water	10 oz.	1000 cc.
Potassium bichromate (1 per cent solution) according to brilliancy desired	6–10 dr.	75–125 cc.

For sepia tones:

Rochelle salt (sodium-potassium-tartrate)	½ oz.	45.5 gm.
Potassium bichromate (1 per cent solution)	4–6 dr.	50–75 cc.
Distilled water	10 oz.	1000 cc.

Development is complete within ten to fifteen minutes. The lengthened time of development will not make the print too dark provided exposure has been correct.

After development the prints are rinsed briefly in water and fixed in:

Hypo	1 oz.	50 gm.
Water	20 oz.	1000 cc.
Ammonia .880	120 min. (2 dr. fl.)	12.5 cc.

after which they are washed for about thirty minutes in running water.[3]

Blue Printing.—Blue printing, now in wide use by engineers for making copies of plans, etc., from tracings, was invented by Sir John Herschel in 1840, and called cyanotype by him. It is a ferric process depending upon the conversion of ferric salt to the ferrous state and the precipitation of Prussian blue by ferricyanide of potassium. Blue print paper can be obtained commercially in 3 grades: fast, medium and slow in most cut sizes and also rolls of various lengths. It does not keep well so no more should be ordered at a time than can be used in two or three weeks.

However, it is easily made and the following directions are given for those who wish to coat their own. Smooth, thin paper is coated with the following solutions:

(*B. J. Almanac formula*)

A.	Potassium ferricyanide	1200 gr.	250 gm.
	Water	10 oz.	1000 cc.
B.	Ferric ammonium citrate	432 gr.	90 gm.
	Water	10 oz.	1000 cc.

For use take equal parts. Both solutions keep well in the dark. The ammonio iron salt must be fresh in order to secure good results. The solution is applied with a brush, working first in one direction and then the other in order to secure an even coating. After drying, it is exposed under the tracing until the shadows are bronzed. Washing in running water for fifteen minutes terminates the process. The use of a ten per cent solution of potassium bichromate increases contrast and enables sufficient contrast to be obtained from weak tracings. As the bichromate solution bleaches the image the paper must be considerably over printed to secure sufficiently dark prints.

By a modification of the above positive prints having blue lines on a white background can be obtained from ordinary tracings in which the lines are in black ink on a transparent white background. Three solutions must be made up.

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[3] For a comprehensive treatment of this and other variations of Kallitype, see Photominiature No. 185 by James Thomson. See also: *American Photography,* 1918, Nov., p. 642.

1.	Water	20 oz.	1000 cc.
	Gum arabic	4 oz.	200 gm.
2.	Water	20 oz.	1000 cc.
	Ammonio-citrate of iron	10 oz.	500 gm.
3.	Water	20 oz.	1000 cc.
	Ferric chloride	10 oz.	500 gm.

The above solutions will keep for a month or six weeks. For use they are mixed as follows:

Solution No. 1	30 parts
Solution No. 2	8 parts
Solution No. 3	5 parts

This is almost clear at first but gradually grows thicker and should be used soon after mixing. It is applied with a brush and it is to be noted that most papers require to be sized beforehand, while most papers do not require any preliminary sizing for the regular blue print process.

After exposure, the print is developed with a brush filled with

Potassium ferrocyanide	200 gr.	104 gm.
Water	4 oz.	1000 cc.

When every detail has appeared and the print is dark blue, rapidly rinse in water and place in a bath of commercial hydrochloric acid (one part to ten parts water) after which it is washed in running water and dried. Positive papers for making copies of drawings, etc., are sold under a variety of names and give not only blue but also black and brown lines on white backgrounds.

General Reference Works

Platinotype

Pizzighelli and Hubl.—Platinotype—English translation by Iselin and Edited by Abney, Published by Harrison and Sons, London.
Horsely Hinton—Platinotype Printing.
Abney and Clark—Platinotype.
The Photominiature No. 7—Platinotype Processes.
The Photominiature No. 40—Platinotype Modifications.
The Photominiature No. 115—Platinum Printing.
George E. Brown—Ferric and Heliographic Processes.
Photominiature No. 10—The Blue Print.
Photominiature No. 47—The Kallitype Process.
Photominiature No. 81—Ozobrome, Kallitype and Blue Prints.
Photominiature No. 185—Kallitype and Allied Processes.

CHAPTER XXII

PRINTING PROCESSES EMPLOYING BICHROMATED COLLOIDS

The Chemistry of Pigment Printing with Bichromated Colloids.—It must be remembered that in all the processes based upon the action of light on a colloid containing a bichromate, the pigment which forms the image is unaltered and plays no part in the reaction. It is just as easy to produce an image in pure bichromatized gelatine as with one containing a pigment, only in the first case the image would hardly be visible unless stained up by the use of dyes. The reaction involved is therefore simply one between light and a bichromated colloid. The salts of chromium are not in themselves sensitive to light; it is only in the presence of light that they are reduced and the action that takes place may, according to the researches of Eder,[1] be represented as follows:

(1) $2K_2Cr_2O_7 + H_2O = 2K_2CrO_4 + Cr_2(OH)_6 + O$

(2) $Cr_2(OH)_6 + K_2Cr_2O_7 = Cr_2O_3 \cdot CrO_3 + 3H_2O + K_2CrO_4$

The first equation may be regarded as the primary light action; the chromium hydroxide $Cr_2(OH)_6$ is decomposed by an excess of bichromate, as in the second equation, to chromate of chromium $Cr_2O_3 \cdot CrO_3$ which is the real agent that acts on organic substances such as gelatine, gum arabic and albumen to render them insoluble in water.

Howard Farmer in 1889 found that in the presence of gelatine, the bichromates are reduced by finely divided silver, so that when a bromide print was immersed in a solution of bichromate, the gelatine in contact with the metallic silver constituting the image is rendered insoluble without exposure to light.[2] This observation forms the basis of both the carbro and bromoil processes. From a chemical standpoint the two processes are essentially the same; the mechanism of the two processes, however, is somewhat different, as in bromoil the insolubilization of the gelatine takes place in the film containing the image, while in the carbro process the insolubilization has to be produced in another layer of gelatine by diffusion.

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[1] *Phot. Korr.*, 1878, 32, 48, 75, 98, 117, 144.

[2] B. P. 17,773 of 1889.

The probable reaction here is first the bleaching of the silver image, resulting in the formation of silver bromide and potassium ferr*o*cyanide. This is reoxidized by the bichromate back to ferr*i*cyanide, the reduction of the bichromate resulting in the insolubilization of the gelatine. With copper salts the reaction is essentially the same, the cupric salt and bromide reacting with the silver image to form cuprous bromide, which is reoxidized by the bichromate into a cupric salt, the reduction of the bichromate resulting in the insolubilization of the gelatine. Hypothetical reactions can, and have been,[3] written to represent these reactions but the objection to all such equations is that while they show what *can* take place, there is little evidence to show that it does take place. Consequently, it does not seem worth while, at the present time, to attempt to represent the reaction in the form of a chemical equation.

The Carbon Process.—Ever since its introduction as a practical process, carbon has been recognized as one of the finest of printing mediums. While it does not allow the same degree of control as some of the later processes, as gum-bichromate and the oil pigment methods, there is a good deal of latitude in carbon printing and if multiple printing is employed alterations of values may be effected to a considerable extent. In common with other processes, which depend upon the action of light upon chromic salts, the carbon process affords a wide variety of colors and surfaces. The Autotype Company, who are the principal makers of carbon materials, supply tissues for over thirty different colors. But even more important is the fidelity with which carbon reproduces the delicate tones of a negative. In this respect it is approached by no other medium and a carbon print will reproduce the fine tones of a good negative more truthfully than any other process extant.

There are two variations in carbon printing known as single and double transfer. In the first case the image is reversed from right to left, while in the latter instance the image is non-reversed. Carbon tissue consists of paper coated with gelatine and pigment. Before use, it has to be sensitized in a solution of potassium bichromate and is then dried in the dark. With the spirit sensitizer, manufactured by the Autotype Company, the drying is very rapid and sensitizing is an operation which requires very little time. When dry, the tissue is exposed to daylight under the negative, a photometer being used to regulate the exposure as the image is not visible. When exposure is complete the tissue is removed from the frame and allowed to soak until limp in cold water. In the meantime, a sheet of single transfer paper, or the temporary support if double transfer is to be made, is allowed to become pliable in the water. As soon as limp, the two are brought together and pressed into contact. After remaining under pressure a short while, the two are immersed in warm water and the tissue stripped off, leaving the gelatine and pigment adhering to the transfer paper, or to the temporary support in case of double transfer. Gentle washing in the warm water follows and the unacted upon bichromated gelatine with its pigment soon washes away leaving the image in pure insoluble pigment. As soon as development is complete, the print is removed, placed in a bath of alum to remove the bichromate stain and harden the gelatine and is finally dried. Double transfer is a little more complicated. After development on the temporary support, the image is hardened and allowed to dry. It is then again placed in water and brought in contact with a sheet of double transfer paper. The two are allowed to dry in contact and the paper may then be stripped from the temporary support carrying with it the image. The introduction of spirit sensitizers has rendered carbon a comparatively simple and straightforward process and instructions unfortunately make it appear more involved than it really is.

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[3] Venn, *Brit. J. Phot.*, 1924, **71**, 427. Tritton, *Phot. J.*, 1927, **67**, 140. Tritton, *Phot. J.*, 1926, **66**, 126. Schömmer, *Phot. Rund.*, 1926, **63**, 210. Schiel, *Phot. Rund.*, 1926, **63**, 55, 97.

Carbon Tissues.—The Autotype Company of England are the principal manufacturers in the world of materials for the carbon process and supply everything necessary for working the process. Over fifty different tissues in thirty colors are made by this company and there are a large number of different transfer papers to select from, giving practically all useful tones and surfaces. The following is a list of the more important tissues of the Company:

Terra cotta
Ivory black
Warm sepia
Standard brown
Standard purple
Gray green
Dark blue
Blue black
Cold bistre
Warm black
Engraving black
Sepia
Red chalk
Ruby brown
Platine black
Italian green
Cool sepia
Portrait purple
Portrait brown
White cameo
Talbot sepia
Sea green
Brownish black
Vandyke brown

Much may be done to enhance the effectiveness of the print by judicious choice of a color appropriate to the subject. Thus, Dark Blue or Sea Green is suitable for pictures at sea or on large bodies of water. Suitable colors for landscapes are found in Engraving Black, Ivory Black, Italian Green, Vandyke Brown, Warm Black and Gray Green. Portraits appear to advantage on Red Chalk, Sepia, Standard Brown, Warm Black and Brown Black. A decided advantage of the colors obtained by the carbon or any other pigment process, over those obtained by toning, lies in the fact that the tones are purer and may be duplicated with ease and certainty which is rarely, if ever, the case with toning processes.

Double and Single Transfer.—Carbon prints from glass negatives are reversed from right to left unless double transfer is employed. In the majority of pictorial subjects this is not objectionable and single transfer is quite suitable. Non-reversed carbon prints may be made from films by printing from the back side and with little or no loss in detail or definition. If carbon printing is proposed at the beginning the negative may be reversed in any one of several ways. The plate may be placed in the plate holder with the glass side facing the lens; a reversing mirror may be used, or the film may be stripped from the negative and reversed. This latter is a rather risky method to employ but some appear to have good success with it. At any rate it is best to use the special stripping plates for the negative as there is then less danger of trouble in the operation of stripping and reversing. On the whole, double transfer is to be preferred to any of these methods where it is necessary that the picture appear in the same manner as seen by the eye; i.e., non-reversed.

Sensitizing the Tissue.—The tissue is supplied in packages of a dozen sheets in nearly all standard sizes and also in bands 2½ by 12 feet. In commercial establishments, the tissue is usually bought by the band but it is more convenient for the beginner to buy the ready cut tissue. Since the tissue tends to curl, it should be kept under pressure until used, and as the solubility becomes less with age until complete insolubility is reached, no more tissue should be purchased at one time than may be used up in a few months at the most.

The sensitizing bath consists of pure potassium bichromate. Only the purest form of this chemical should be used. That sold for storage batteries, etc., is unsuited. The strength generally advised for average negatives is four per cent solution, although with weak negatives better results will be secured with tissue which has been sensitized in a bath of lower concentration, as 2 per cent or 3 per cent. The sensitiveness depends upon the strength of the sensitizing solution and also upon the tissue. Thus tissue sensitized in a 1 per cent bath of potassium bichromate requires about three to four times more exposure than that sensitized in a bath of 4 per cent, while a color such as Red Chalk requires more time for exposure than turquoise blue, owing to its greater opacity to actinic light. However, generally speaking, the tissues all require about the same exposure.

On the whole, the use of the Autotype Company's Spirit Sensitizer is to be advised for the amateur or occasional worker. For commercial work, where the proper facilities are available for drying the tissue after sensitizing, the plain bichromate bath is satisfactory but as these are generally not at the disposal of the amateur, it is recommended that he make use of the spirit sensitizer, which dries very quickly, requiring no elaborate drying cabinet, and permits the tissue to be used within an hour.

In place of the spirit sensitizer of the Autotype Company the following may be used:

Ammonium bichromate........................	60 gm.	460 gr.
Water to make................................	1000 cc.	16 oz.

This is a stock solution one part of which should be diluted with an equal volume of alcohol. The diluted solution will not keep. The tissue should be immersed in the diluted sensitizer for five minutes, then removed and treated as described later.

A more sensitive tissue requiring from one half to one third the exposure of that sensitized with bichromate alone can be prepared by adding to each 100 parts of a 2½ per cent solution of potassium bichromate 2 parts of a 10 per cent solution of cerous chloride.[4] Immersion of the exposed tissue in a 2 per cent solution of cerous chloride before transfer, however, is equally effective as regards decrease of exposure and is more satisfactory in practice.

The operation of sensitizing with a spirit sensitizer is as follows: Pour an ounce or two of the sensitizer into a saucer or cup and dip the Blanchard brush, supplied with each bottle of sensitizer, in the same and then apply to the tissue which should be pinned down on a board with pushpins. The solution must be evenly distributed and *rapidly* as it dries quickly. First cover the tissue lengthways and then dip the brush in the solution again and go over the tissue a second time in the opposite direction, namely the short dimension. For a large print, a special brush should be made in order that the surface may be more rapidly covered with the sensitizing solution. When the first sheet of tissue is surface dry (several sheets may be coated in the meantime), it should receive a second application in order to insure a uniform coating. When finished throw away the remaining sensitizer and wash out the brush and keep for future use. The sensitizing bath should be kept in the dark when not in use. The tissue should be hung on a line in a dark room to dry, which will take from ten to twenty minutes. The use of an electric fan will hasten drying as will also moderate heat. Of the two, the first is the safer, as heat may render the tissue insoluble. The tissue should be thoroughly dry before it is placed in the printing frame. If it is intended to keep the tissue for any time, it should be placed in the storage tube supplied by the Autotype Company. Sensitized carbon tissue is at its best, however, as soon as dry and can only be kept in good condition with safety for a week or so, even in the special storage box.

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[4] Tritton, *Brit. J. Phot.*, 1929, **76**, 381.

The tissue may also be sensitized by immersion but then requires much longer to dry. It is, however, more sensitive than that sensitized by brushing and increases in sensitiveness with age.[5]

Exposure.—No special type of printing frame is required, but since there is no necessity for examining the print during exposure, the back need not be made in two pieces as usual.

The tissue must be kept dry while exposing and for this purpose sheets of waxed paper or waterproof sheets of vulcanized rubber, as used for the same purpose with platinotype, may be employed. The springs of the frame need to be strong and for this reason many of the cheaper frames known as " Amateur " will be found unsatisfactory since the springs are weak and unable to hold the rather stiff pigmented tissue in perfect contact with the negative.

Printing is usually done in the shade as the direct rays of the sun may crack or cause the tissue to become insoluble. For commercial work, the Cooper-Hewitt mercury vapor lamp is a satisfactory light.

Before printing, the negative should be provided with a " safe edge." This is a narrow opaque border on all four sides of the negative which insures a soluble margin to the picture by protecting the tissue from the action of the light. This " safe edge " may consist of a strip of opaque paint on the negative or the black paper masks sold for the purpose of producing prints with white borders.

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[5] For methods of sensitizing using dyes, see Meisling, *Brit. J. Phot.*, 1916, **63**, Feb. 23; *Dansk. fotografisk Tidskrift* Nos. 9 and 10, 1916; Warburg, *Phot. J.*, 1917, **57**, 169.

As the image is invisible, an actinometer is used to gauge the time of exposure. Several forms are obtainable. Three popular types, Burton's, Sawyer's, and Johnson's, are illustrated in Fig. 188.

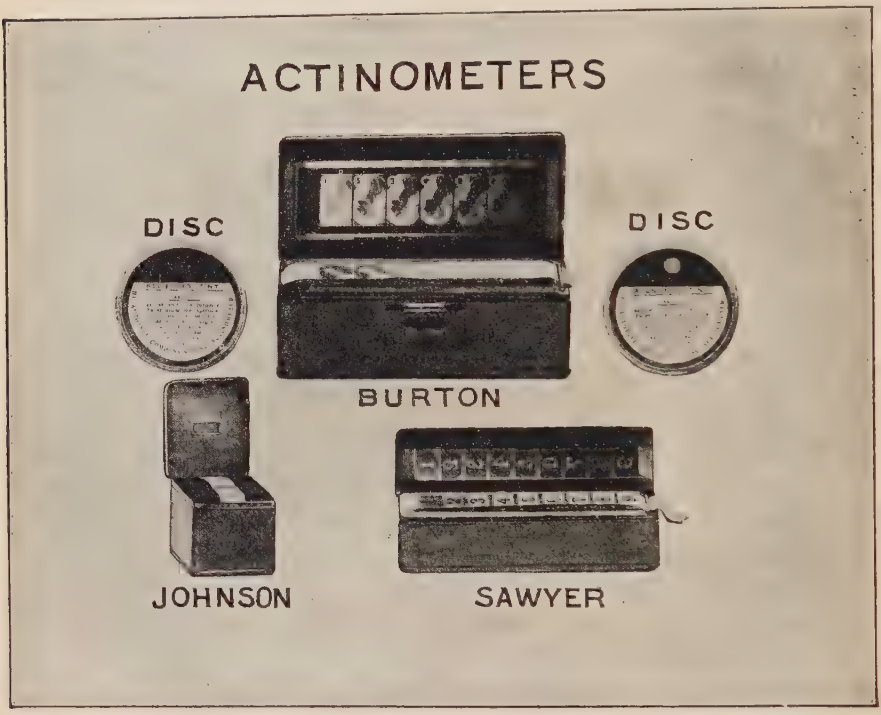

Fig. 188. Actinometers for Carbon Printing

In Johnson's actinometer a small roll of sensitive paper is contained within the cubical box. This is pulled forward and exposed to light beside the frame until the tint of the paper and the standard tint register and a new piece pulled into position. A thin negative may be sufficiently exposed in one tint, a medium one in two or three, while denser ones range higher. Such actinometers are known as intermittent and are not so convenient as the continuous type of which the Sawyer is an example. In this instrument there is a graduated scale of increasing opacities ranging from 1 to 9. The paper is exposed beneath the graduated scale and each number darkens in succession to the standard tint so that there is no necessity for moving the paper during an exposure. The Burton instrument is similar but has several portrait negatives of increasing density. Sensitive paper is placed under the negative in the actinometer which appears to resemble in density the negative to be printed and the two exposed until the test paper appears sufficiently dark.

Carbon tissue sensitized on a 4 per cent bath of potassium bichromate is about three times as rapid as P-O-P. The beginner will find it necessary to make two or three tests and after development the proper exposure can be judged. The number of "tints" required may then be marked upon the negative so that the proper exposure at any future time can be readily determined with the actinometer.

After exposure the print should be developed as soon as possible as if left to stand the action of light will continue even though the print be kept in complete darkness and over exposure will result. This is known as *"the continuing action of light"* and was first observed by Johnson, and Abney later showed that the principle might be used to advantage in increasing the speed of printing in dull light. It is possible to work out a system whereby one third or even less of the original exposure may be given and the print allowed to stand several hours before development. Unless absolutely uniform conditions can be maintained, this method is not to be advised however and the beginner will do well to develop immediately after exposure.

Development.—The development of a carbon print is a comparatively simple operation. No chemicals are needed, hot water and a large tray being the principal requirements. No dark room is required and the operation may be carried out in subdued daylight. Up to this stage there is no difference in double or single transfer but before development it becomes necessary to transfer the pigment to either its transfer paper or to a temporary support from which it will later be again transferred to its final support. Transfer is necessary because the insoluble pigment which has been formed by the action of light is upon the *surface* of the tissue while the insoluble pigment which must be washed away in order to reveal the image lies beneath the image. It is, therefore, necessary to transfer the pigment so that the soluble pigment will be on top where it can be washed away without affecting the pigment forming the image.

We will first consider single transfer as it is the simplest and best for the beginner. After he is able to make single transfer prints with satisfaction, he may experiment with double transfer.

A sheet of single transfer paper is placed in cold water at about 60° F. (16° C.) for several minutes until it is limp.[6] The exposed tissue is then placed in the same water. The tissue will at first curl inward and then outward until it becomes practically flat. At this point it should be removed from the water and placed face down upon the transfer paper, which should have been previously placed upon a flat surface with the side coated with gelatine upwards. When the two are in contact, a squeegee is passed over the same from center to the margin with moderate pressure in order to eliminate air and moisture. After being squeegeed into contact the tissue and its support may be placed under blotters and allowed to remain for fifteen to twenty minutes before development.

To develop, immerse the print and its support in water at about 95 to 100° F. (35–38° C.). In a few seconds the pigment will begin to ooze out around the edges. When this begins, separate the corner of the tissue and its support by lifting it with the finger nail and pull off the paper that originally held the pigmented gelatine. This tissue may be discarded. Holding the print by one corner, gently splash warm water over the surface. The soluble pigment will gradually wash away leaving the image. Care should be taken not to touch the print with the hands or any hard substance as the gelatine is very soft and easily injured at this stage. If the print is under exposed, the pigment will wash away very easily while if exposure is excessive the pigment dissolves with difficulty and warmer water must be used. Highlights may be lightened or detail in dark shadows may be brought out at this stage by squirting water from a blow tube against the print, or hot water may be poured on the desired portion.

When development is complete, place the prints in clean cold water for a minute and then transfer to a five per cent solution of alum to remove the bichromate stain and harden the gelatine. Porcelain steel enamelled or hard rubber trays may be used for the alum solution but tin or zinc vessels, such as may be used for development, are to be avoided. The time required in this bath varies but sufficient time should be given to make sure that all of the bichromate stain has been removed as any trace which is left will be more noticeable when dry than while wet.

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[6] Very rough or thick transfer papers should be allowed to soak for an hour before being squeezed into contact with exposed tissue. With thin and smooth papers ten to fifteen minutes will be sufficient.

After clearing and hardening in the alum bath, the print is removed and well rinsed in water and then hung up to dry. Carbon prints should not be forced in drying by heat as there is a danger of the gelatine cracking. An electric fan, however, may be used to hasten the process.

Double Transfer.—So far we have considered only single transfer which is quite suitable in all cases in which reversal of the image is not objectionable. The operations prior to development are the same in both single and double transfer. Before development, instead of being attached to the transfer paper, the exposed carbon tissue is fixed to a temporary support. This temporary support may be opal glass or the specially coated paper supplied by the Autotype Company. This latter product is made in two grades: Thick No. 112 for general use, giving either medium gloss or matt; and Thin No. 112 which is advised for thick and rough surfaced transfer papers.

Before use, the support must be waxed so that the gelatine image may be stripped from the temporary support without danger when transferring to the final support. The waxing solution consists of one part of beeswax and three parts of resin dissolved in turpentine and may be purchased especially prepared. Several drops of this waxing solution are poured on the temporary support and gently rubbed over the surface using a pad of flannelette. The waxing is a simple operation but care must be taken that the support is evenly and thoroughly waxed. Unequal distribution gives rise to a difference in surface texture on the finished print as some sections will have more gloss than others. If a part of the support has not been covered at all the gelatine may adhere and the print will then be spoiled. An hour or so must be allowed after waxing before the supports are used in order to allow the turpentine to evaporate. It is an excellent plan to wax the supports several hours, or on the day before they are to be used.

There is less latitude in development with double than with single transfer and the exposure should be as nearly correct as possible in order that very hot water may not be necessary for development. There is a tendency for the image to blister while on the temporary support which is due to a softening of the wax and the use of hot water, of course, will cause the wax to soften more than cold.

The temporary support is placed in water along with the exposed tissue and allowed to remain until it becomes comparatively flat. The exposed tissue is then squeegeed to the waxed side of the temporary support and allowed to remain under pressure for several minutes after which it is developed in exactly the same way as single transfer. After development, the temporary support with its adhering image is placed in the alum bath to discharge the bichromate stain and harden the gelatine after which it is rinsed and allowed to dry. Care should be taken not to injure the delicate surface during any of these operations. Dry the image in a cool place—not in the sun nor by any kind of heat.

When dry, the operation of transferring the image to the final support may be proceeded with. For this purpose double transfer paper is supplied in a wide variety of tones and surfaces. The sheet of double transfer paper should be larger than the temporary support, say 7 x 9 for 5 x 7 print. It is placed in cold water and allowed to soak for an hour in order to swell the gelatine coating so that the image will adhere. After soaking for an hour remove and place for a minute or so in water at about 90° F. until the surface feels slimy to the touch after which it is again returned to the cold water where it may remain until required. The dry print on the temporary support is now placed in cold water until flat and limp and is then taken out and placed face up upon a smooth flat surface as a sheet of plate glass. The sheet of softened double transfer paper is then placed on top of it and held in place by one hand while the two are squeegeed into perfect contact with a flat squeegee. The pressure must be sufficient to force out the water but not so great as to affect the gelatine. A few trials will serve to show the proper amount of pressure to apply. The temporary support and double transfer paper are then hung up on a line to dry. When thoroughly dry, insert the point of a knife blade under one corner and pull the two apart, when it will be found that the image leaves the temporary support and adheres to the double transfer paper. If the plate has not been properly waxed, the image may adhere to the temporary support in places and the print ruined. This may also happen if the gelatine coating of the double transfer paper has not been sufficiently softened before use.

Transferring to Rough Papers.—It is strongly advised that the beginner stick to smooth surfaces until he is perfectly sure of himself. However, the carbon image can be transferred to very rough surfaces as Whatman's hot pressed drawing paper, but greater care and familiarity with the process is required and for this reason the beginner will do well to stick to smooth and moderately rough surfaces for quite a while. The temporary support to use is No. 112 thin. The image on its temporary support is placed in water for several minutes and allowed to become limp. It is then removed and immersed in the gelatine solution which is prepared as follows:

Soak one ounce of Nelson's gelatine No. 1 in 20 ounces of water for fifteen minutes. Then heat the solution to about 115 to 125° F. until the gelatine is melted. To an ounce of water add 5 grains of chrome alum and when dissolved, add to the solution of gelatine, stirring well all the while. The gelatine solution should be strained through muslin before use.

A piece of the transfer paper, which has been soaking in water for an hour or more, is then removed and placed face up on a smooth, flat surface. The print on its temporary support is removed from the gelatine solution and placed face down upon the transfer paper and the two squeegeed firmly into perfect contact. Clean the margins of the transfer paper, which should be an inch or so larger than the temporary support, and hang the prints up to dry. When thoroughly dry, they may be stripped off as usual. Any slight smoothing of the rough surface, due to being in contact with the smooth waxed temporary support, may be removed by soaking the print in water for half to three quarters of an hour and redrying.

The Carbro Process.—The carbro process has a number of noteworthy advantages over the older method of carbon printing and will no doubt serve to increase the popularity of pigment printing. Unlike carbon no daylight is required at any stage so that the difficulties of drying the tissue and exposing to daylight are avoided. This greatly simplifies the production of pigment prints and by rendering the worker independent of daylight enables him to use his evenings in printing. There is in addition the advantage that an enlarged negative is not required when prints are desired larger than the original negative, since from a good bromide enlargement any number of carbros in reason may be made without loss of quality. In these days of small cameras and dependence upon projection printing the possibility of using a bromide enlargement instead of an expensive enlarged negative is a matter of some moment and this point weighs heavily in favor of the carbro process. As a carbro print is identical with a carbon print made from the negative by the usual method, it is evident that we have in carbro printing the same range as regards color and texture that we have in carbon, and, since the finished print is the same in both cases, the same features of artistic excellence for which the carbon process is noteworthy. Added to this there is the possibility of multiple printing, which is simpler in carbro than in any other process. There is one objection to the carbro process which makes it technically inferior to direct carbon prints made from the negative, and that is the loss of critical sharpness. This, as pointed out by Namias,[7] is due to the fact that the image is detached from the pigmented layer of gelatine and there is a local spreading of the action owing to the lateral diffusion of the insolubilizing agent within the pigmented gelatine. However, for all but the most critical scientific work where extreme sharpness of minute detail must be preserved, the slight softening of the outlines is unobjectionable and in the case of pictorial work may be actually an advantage.

It is therefore not too much to say that carbro represents a notable advance in carbon printing. It is deserving of the attention of every serious amateur and professional and will, no doubt, do much to revive the waning interest in the carbon process which remains, as it has always been, one of the finest of positive printing processes.

The Bromide Print.—Since in carbro printing the bromide print acts as the negative, its preparation should be with the same care and attention which would be bestowed on a negative. As regards the make of paper, nearly all commercial brands of bromide appear to be suitable. The times of immersion in the various baths, however, differ with various brands of papers, but this is a matter of minor importance since the time of immersion once determined for a given brand remains constant, within small variations, for succeeding batches of the same paper. On the whole the platino matt or semi-matt surfaces are perhaps the best grades to employ as they are easier to work with and give a larger number of prints. Gloss papers, however, may be used as well as the rough grades. In the case of very rough surfaces there is some difficulty and until the worker is thoroughly familiar with the process he will do well to avoid such papers.

The bromide print should receive full but not over exposure and must be fully developed. The factorial method of development already advised for bromide prints is strongly recommended for the development of the original bromide to be used for carbro printing. A slight burying of the shadows in the bromide print is not an objection since, owing to the superior gradation of carbon in the shadows, such gradations, although lost in the bromide, will be visible in the carbro print.

While in general bromide papers yield the finest results, gaslight papers may be used when necessary. In this case the gaslight print should first be bleached in the usual ferricyanide-bromide bleach as used for sulphide toning and redeveloped in amidol or metol-hydrochinon. It will then produce carbros equal in every respect to those made from bromide prints. The use of gaslight paper is at times desirable when owing to the character of the negative it may be impossible to get a print of the required contrast on bromide paper.

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[7] *Brit. J. Phot.*, 1913, **60**, 141.

As in carbon, it is necessary to provide the bromide print with a "safe edge" by leaving a white margin of ¼ to ½ inch all around the print.

Where the water supply contains lime, it is well to place the print, after fixing and washing, in a solution of hydrochloric acid and water (3 parts concentrated HCl to 100 parts of water) for 5 minutes, then wash for ten minutes. If this is not done there is a danger that the lime formed within the bromide print will prevent complete bleaching of the highlights with the result that they wash away in the development of the carbro.

Should any spotting be required, or it is desired to darken certain portions in such a way that the result will be reproduced in the carbro print, one may use water color containing Indian ink. All such alterations are reproduced in the carbro print with as complete transference as any other part of the image.

Sensitizing the Carbro Tissue.—For this purpose the following stock solutions are required:

Concentrated Solution No. 1:

Potassium bichromate	1 oz.	10 gm.
Potassium ferricyanide	1 oz.	10 gm.
Potassium bromide	1 oz.	10 gm.
Water to make	20 oz.	200 cc.

Concentrated Solution No. 2:

Glacial acetic acid	1 oz.	10 cc.
Hydrochloric acid (pure)	1 oz.	10 cc.
Formaldehyde 40 per cent	22 oz.	220 cc.

The addition of 1¼ oz. or 12 cc. of water to the above will prevent precipitation in cold weather.

For use take:

First Bath:

Concentrated No. 1 stock solution	6 oz.	100 cc.
Water to make	18 oz.	300 cc.

Second Bath:

Concentrated No. 2 stock solution	1 oz.	10 cc.
Water to make	32 oz.	320 cc.

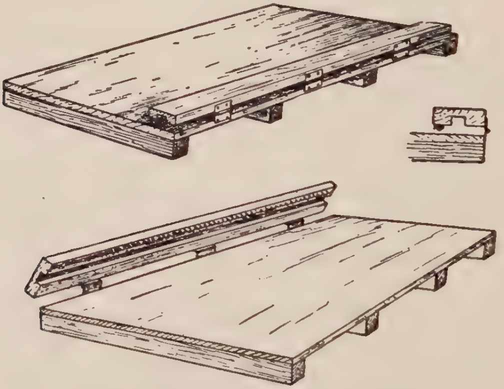
The above English and metric weights are not equivalent but are proportionate.

The first bath may be used for some time, fresh solution being added as its bulk grows smaller. The second bath, however, should be frequently renewed as it is altered by the No. 1 solution which is carried over into it.

Both concentrated solutions keep well in tightly corked bottles away from light. The temperature of the working bath should be kept as nearly as possible at 60–65° F.—a lower temperature will lessen the activity of the solutions while a higher one will increase their activity and bring on various troubles.

Sensitizing the Pigmented Tissue.—The working baths having been made up, the sheet of carbon tissue is immersed in No. 1 bath by sliding it under the surface of the solution. Remove any air-bells on the face of the tissue and then turn it face downwards. After two minutes the pigmented tissue should be again turned face upwards and allowed to remain for another minute. Then lift it up by the corner and let it drain for 15 seconds. Finally grasp it by two corners and slide it face up into solution No. 2.

The time of immersion in this second bath is governed by the effect desired and by the brand of bromide paper employed for the print. It is impossible to give the best time for immersion since so much depends on working conditions, but as a rule the time ranges from 15–30



The upper drawing shows the hinging of the clamping strip at the requisite height above the base. In the lower drawing is indicated the edging of studded rubber.

Fig. 189. Squeegee Board for Carbro. (Farmer)

seconds. The shorter the time of immersion the greater the contrast of the carbro print, while with longer times of immersion the less the degree of contrast. It is thus possible by varying the time of immersion in the second bath to produce a print having the same degree of contrast as the original, or one having increased or diminished contrast. Thus if under a given set of working conditions 20 seconds immersion produces a carbro print identical with the original bromide, 15 seconds immersion will produce a carbro having *greater* contrast and 25 seconds *less* contrast than the original. It is obvious that such control may be employed to control the gradation of the carbro print so as to secure exactly the *brilliancy* desired.

The number of seconds decided upon having elapsed, the pigmented tissue is lifted from the bath and laid upon the bromide print which should have been previously soaked in water for ½ hour and laid upon a sheet of glass or upon the squeegee board illustrated in Fig. 189. Once the two are in contact their relative positions must on no account be altered as the action begins immediately and a change in position would produce a blurring of the image. As soon as the pigmented sheet is in contact with the bromide print a rubber squeegee is brought into play and the superfluous water forced out by firm, straight strokes.

The bromide print with its adhering sheet of carbon tissue is then lifted from the glass or squeegee board, placed between greaseproof paper and allowed to remain for 15 minutes for the action of the insolubilizing solution to take place.

Transfer.—In the meantime a sheet of transfer paper of the desired grade should be placed in cold pure water and allowed to soak for at least 5 minutes if thin, or 10 minutes if thick. Then, at the expiration of the fifteen minutes, strip the pigmented tissue from the bromide print, drop the bromide print in clean running water, and place the pigmented tissue on the transfer paper, squeezing the same so as to secure perfect contact. Finally place between blotting papers under slight pressure and allow to remain for 20 to 40 minutes.

Redevelopment of the Bromide Print.—While this is being done the washing of the bromide print may be attended to and when thoroughly washed it is redeveloped. For this a plain metol developer is advisable although metol-hydrochinon may be used. Care should be taken in any case that development is thorough and to this end it is well to leave the bromide print in the developer several minutes longer than would be judged necessary from its appearance. Fixing is unnecessary and after washing and drying the print is again ready for carbro printing.

Development of the Carbro.—The development of the carbro is much the same as the development of a carbon print made by the older method. The transfer paper with its adhering sheet of pigmented tissue, the latter uppermost, is placed in a large dish of warm water at a temperature of about 95° F. (35° C.). This is somewhat lower than the temperature found necessary for carbon and is due to the fact that the soluble gelatine leaves the image at a lower temperature and more rapidly than with a carbon print made in the ordinary way. One should not attempt to judge the temperature of the water by the finger but use a thermometer. In a few minutes the pigment will begin to ooze out around the edge; when this occurs, separate the transfer paper and the paper backing of the pigmented tissue and gently strip the latter off and throw away. If the pigment shows a tendency to stick to the tissue backing so that parts of the image are pulled up from the final support, the tissue is old and warmer water should be used for stripping. The paper backing having been removed, grasp the print by one corner and gently splash water over it with the other hand. As the pigment is very soft at this stage, on no account must the image be touched or treated with any violence whatever. If after a short while the print is still too dark, warmer water may be used. There is quite a little control possible in development by the use of colder or warmer water. It is best, however, to resort to this only when other agencies have been exhausted.

If it is desired to lighten any portions this may be accomplished by pouring on such portions a thin stream of warmer water, taking care, however, that the force of the same is not so great as to wash up the image. By this means a highlight can be brightened or a heavy, blocked up shadow lightened so as to bring out buried detail.

When development is judged to be complete, the print is removed, raised in clear cold water and placed in a 5 per cent solution of alum. This removes the yellow stain left behind by the bichromates and ferricyanide and hardens the image. Care should be taken that the action of the alum is complete as the yellow stain is much more apparent when the print is dry than when wet. In commercial practice it is well to use two baths of alum; immersing the print until apparently clear in the first, then transferring to the second for 3 or 4 minutes.

After removal from the alum bath the print should be rinsed well in cold water and hung up to dry. Heat should not be used to hasten drying.

Carbon on Bromide.—If desired the pigment image can be developed on the bromide print instead of transferring to a new paper support. The procedure is just the same except that when the fifteen minutes of contact between the bromide and the pigmented tissue have elapsed, instead of stripping off the pigmented paper, both it and the bromide print are placed in warm water and developed as already described. The print then consists of a pigment image over the bleached image of the bromide print. This last may be allowed to remain, redeveloped or removed by means of the ordinary ferricyanide-hypo reducer.

As the yellow color of the bleached image alters the tone of the finished print and since it darkens slightly on exposure to light it is advisable either to redevelop the bromide image or to remove it completely. Redevelopment of the silver image darkens the print since in this case the resulting print has the depth of the two images; one of silver and the other of carbon. This property may be used to advantage in dealing with weak negatives from which it is impossible to get sufficient richness in the ordinary way.

Multiple Printing.—The first, I believe, to call attention to the simplicity of multiple printing by the carbro process was Paul L. Anderson in the *American Annual of Photography* for 1923, p. 44. I repeat his remarks on the subject:

> Multiple printing by the non-transfer method (carbro on bromide) is ridiculously easy, for whereas registration marks are necessary in the transfer method, no such precautions are required in non-transfer; the second sheet of sensitized tissue is squeezed down on the redeveloped bromide and the silver image itself takes care of registration. The writer has never put more than three printings of carbon on one bromide, but there seems to be no reason why an indefinite number should not be applied if necessary: however, three will generally take care of any desired effect.

It is obvious that multiple printing may be employed for the purpose of printing one color over another, or for increasing the range of gradation and adding to the finished print a quality which cannot be secured by a single printing. As was shown by Hubl as early as 1898 in regard to the gum-bichromate process,[8] the very best results are obtained from a long-scale negative when two or more prints are made and superimposed; one print being soft and the other contrasty. In this way is obtained "a result which often surpasses, in truth and fidelity to the original, a normal print from the negative."

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[8] Eder, *Das Pigmentverfahren, der Gummi-, Oel und Bromoldruck,* Halle a/S, 1917.

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CHAPTER XXIII

THE GUM-BICHROMATE PROCESS

Introduction.—The gum-bichromate process is another of the several processes which depends upon the fact that chromatized colloids become insoluble upon exposure to light. It differs from carbon in that the colloid used is gum-arabic instead of gelatine and also that there is no transfer, the print being exposed and developed from the front, which renders multiple printing necessary in order to secure a full scale of gradation. Gum is without doubt one of the most flexible printing processes known and can far surpass any other in quality in the hands of a worker who understands it and knows how to get what he wants. Almost any degree of contrast may be obtained and local values may be altered to suit the artistic sense of the worker. As in carbon there is a wide variety of colors available and also an even wider range of surfaces from which to choose. The scale of gradation which may be secured by multiple printing is greater than any other process can render. Aside from these there is a quality in a good gum print, particularly in the shadows, that makes it superior to all other printing mediums with the exception of photogravure and possibly the oil processes. The shadows can best be described by saying that they have *depth* and richness, without any gloss or muddiness. For the worker who takes a pride in the artistic quality of his work and whose desire is to turn out a few good prints rather than a great many, gum is an ideal process.

Owing to the coarse grain of the gum coating, small detail is destroyed so that the process is only suited to broad subjects having no important detail—such as the artist calls "big" subjects. For the same reason, gum is at its best in large sizes, 8 x 10 and larger. As the paper is not sufficiently sensitive for enlarging, an enlarged negative must be made and this is a handicap to many workers as is also the fact that exposure must be to daylight. A great deal of painstaking care and attention is required at each and every stage of the various operations of coating, exposing, and drying, and as these have to be repeated at least twice and often as many as five times in order to secure prints having the proper depth and quality, the process is a lengthy one and one which demands the energies of the worker for a longer space of time than many can spare from their other occupations.

Materials.—The papers which can be advised for the process are: "Griffin" detail paper of Seltmann of New York City, Strathmore detail made by the Mittineague Paper Co., Whatmans, Michallet, Allonge, Lallane and English cartridge paper, practically all of which may be had from paper dealers in the larger cities. Handmade paper is to be preferred to machine made, as it is tougher and has not been strained in manufacture so that the fibers do not all run in one direction.

The colors used are the moist water colors sold in tubes. The makes of Devoe and Windsor and Newton are to be recommended. For a beginning, one or two tubes each of ivory and lamp black will do, while the following seven colors: ivory, black, lamp black, Venetian red, chrome yellow and Prussian blue, will cover practically all normal requirements.

In addition to the paper and color, several trays about a size larger than the largest print will be required; also two or three graduates (about 8 and 16 ounces); a supply of glass-headed push pins; several ounces of granulated gum-arabic; two brushes, one a rubber bound for coating and the other a broad soft brush for blending; and a board about twice the size of the paper to coat.

The Negative.—The negative calls for little attention as owing to the personal control which may be exercised in printing, any variations in contrast can be made, according to the taste of the worker. However, a thin negative seems to print better than a dense one, even though they may be practically identical in other respects. Of course, it is best to aim at a technically perfect negative having normal contrast and with minimum density, but by multiple printing the shadows may be printed in one operation, the half tones in another and finally the highlights in a third, so that the final result is completely under the control of the worker.

Formulas.—

GUM SOLUTION

Water	12 oz.	1000 cc.
Gum-arabic	2200 gr.	366.6 gm.
Arrowroot	270 gr.	44.6 gm.
Mercuric chloride	15 gr.	2.5 gm.

Dissolve the mercuric chloride in a small amount of water and then add the arrowroot, stirring the same until a thin cream is obtained. Then add the remaining water and the gum-arabic. The latter will dissolve more rapidly if suspended in the solution by means of a cheesecloth bag. From sixteen to twenty-four hours will be required for the latter to completely dissolve.

Sensitizing Solution

The stock solution of sensitizer consists of a solution of potassium bichromate:

Water (hot)	15 oz.	1000 cc.
Potassium bichromate	720 gr.	96 gm.

Both of these solutions keep well.

The actual mixture used for coating varies with the paper and the negative and also with the effect desired. Practically every worker develops a different formula after practice and while there may be little difference, yet it is better adapted to his own personal methods of working.

However, the following formulas are given for the benefit of the beginner:

Shadow Coating

Gum solution	½ oz.	15 gm.
Sensitizer	½ oz.	15 gm.
Ivory black from tube	4 in.	4 in.

If the negative has a short scale of gradation it may be possible to use the above for all of the printings; if, however, this is not the case and the negative has a long scale of gradation and prints well with bromide or platinum, then it will be necessary to vary the coating mixture so as to secure a longer scale. It is generally necessary to make three printings: one for the shadows, another for the halftones and finally one for the highlights. The following are advised for the halftone and highlight coating mixtures:

Halftone Coating Mixture

Gum solution	½ oz.	15 gm.
Sensitizer	½ oz.	15 gm.
Ivory black from tube	2 in.	2 in.

Highlight Coating Mixture

Gum solution	½ oz.	15 gm.
Sensitizer	5 dr.	17.75 cc.
Ivory black from tube	1 in.	1 in.

Effect of Varying Proportions of Coating Mixture.—Although the above may be regarded as an average formula, considerable variation is possible, but the beginner will do well to stick by the above until he is familiar with the process and knows what steps to take in order to secure the desired result. Increasing the amount of pigment gives a longer range of tones but the whites are stained and lack purity. An excess of gum makes the coating hard to blend smoothly and produces a thick film which may chip off in development. A moderate increase in the amount of gum solution gives greater contrast and the highlights may be blocked. An excess of sensitizer gives a coating which is difficult to spread and one which gives flat, lifeless prints. A rough paper will take a thicker coating than a smooth one and is also more easily coated so that the latter is not to be recommended for the beginner.

Figure 190 gives schematic curves for gum pigment with varying amounts of gum, pigment and sensitizer. Examination of the same will show that (1) has a long scale of tones with little contrast, (2) shows a shorter scale of tones with greater contrast, while (3) shows a short scale of tones with high contrast. This gives an idea of the immense variation which may be produced in a single printing by alterations in the composition of the coating mixture. Further variations may be made by using different coating mixtures for the different printings and by local control, so for these reasons it may be readily seen that gum is justly regarded as one of the most flexible processes which we have for the production of positive prints.

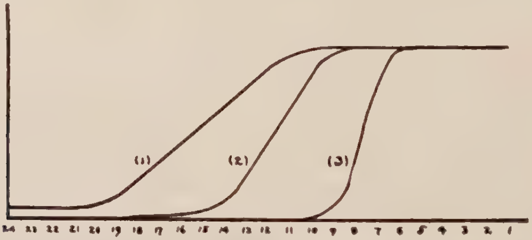

FIG. 190. Curves Showing the Influence on Contrast of Variations in Proportions of Gum, Pigment and Sensitizer in the Gum-Bichromate Process (Anderson)

Coating.—The coating mixture having been prepared, the sensitizing of the paper may proceed. Rough papers are the easiest to coat and the beginner is therefore advised to start with a rough paper, as

Whatman's. The sheet should be larger than the negative as it is next to impossible to secure a perfectly even coating to the very edge of the paper. A sheet 11 x 14 will be suitable for either 8 x 10 or 10 x 12, while an 8 x 10 sheet is sufficiently large for a 5 x 7. Attach the paper to the drawing board with push pins and pour the coating mixture in the center. The paper will be more easily coated if it is immersed in water and blotted before being placed on the board. For the first 11 x 14 sheet of paper, about one half ounce of the coating mixture will be required, while succeeding sheets will require somewhat less, owing to the brushes becoming charged with the gum. The rubberset bristle brush is used to spread the coating over the paper so that every part is covered with the coating mixture. When this has been done, the blender comes into play. There are two brushes which may be used for blending (one made of fitch and the other of badger) and the details of the operation depend somewhat upon which is being used. With the former the brush is held nearly vertical and drawn slowly and regularly across the paper—always in the same direction. When the sheet has been covered in one direction, it is again gone over in the opposite direction, to secure a perfectly even coating. With the latter, the action may be " whippy," the vigorous handling of the brush lessening as the operation proceeds. The exact manner of handling the brush and the time to stop blending will come with a little experience. In general, it may be said that when the point is reached where the tendency of the gum solution is to run into small puddles, the operation should be stopped whether the surface appears completely even or not. Any irregularity will disappear in drying or development or will be covered by subsequent printings. As soon as the operations are complete the utensils should be washed free from the gum solution, as it is very difficult to remove when dry.

Drying.—The paper may be dried in a dim light, provided it is to be used as soon as dry. The paper is insensitive when wet but becomes sensitive when dry. However, if the paper is to be stored for any length of time, it should be dried in the dark as the action of light continues, and the gum will become completely insoluble unless it is dried in a dark place. The time of drying will depend altogether on the temperature of the room, but with an ordinary room temperature of 65 to 75° F. (18–24° C.), the time required should not be over an hour or so. If not for immediate use, it should be placed in an airtight container, similar to platinotype, for storage. The paper is at its best when fresh.[1]

Exposure.—As the image is invisible a photometer must be used to gauge the time of exposure. The photometers illustrated and described in the former chapter on carbon printing are suitable for the purpose and the serious worker should secure one of these. When the light is steady, the frame may be loaded with proof paper and the time required for reaching the desired depth noted and the gum paper exposed directly afterward for the same length of time. Since, however, it is rare that the light is uniform, the use of an actinometer is to be advised. There is a good deal of latitude in exposure but correct exposure will greatly simplify development and give the best results. Over exposure is preferable to under exposure, as the development of the former may be forced by the use of hot water or an alkali, while the latter once in the developer is useless. If it is known that the print is under exposed, it may be laid away for several hours before development. The action of the light continues in the same manner as in carbon printing and this method may, therefore, be used with advantage when the light is dull and long times of exposure are required. But since it is difficult to determine the exact rate at which the action proceeds, it is preferable to expose fully and develop in the normal manner.

Development.—One of the "talking points" for the gum-bichromate process when first introduced was the ease with which local values might be altered by the use of a brush or sawdust, etc., in development. While, to a certain extent, local work of this nature is now done, most workers now content themselves with automatic development. The exposed print is immersed face up in a large tray of cold water and as soon as limp turned face down, care being taken that no air bells are imprisoned beneath it, where it is left with an occasional examination, for one half to one hour. If the image is completely developed within ten or fifteen minutes the print is under exposed and may as well be thrown away. If the image does not appear within one half to three quarters of an hour, the print has been over exposed and the temperature of the water may be raised slightly. The use of an alkali is not to be advised when multiple prints must be made, nor should the temperature of the developer be raised over 90 degrees. It is better to prolong the time than to raise the temperature or resort to an alkali in such circumstances. When the solution which drains from the print, when removed from the water, is practically clear, development may be considered complete and the print placed in a *horizontal* position to dry, care being taken that nothing comes in contact with its surface until dry. When dry it is ready for the sensitizing, exposure, etc., for the second printing.

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[1] Heat may be used for drying but not at a higher temperature than 180° F (82° C.).

To lighten any local portions the print may be held under water and a stream of water from the tap allowed to fall upon the desired portion, or an atomizer used. Greater emphasis may be secured by using hot water or by holding the print so that the stream of water falls directly upon the surface. Local values may also be lightened by the use of a very soft brush. There is a tendency for brush work to show graininess and for that reason it should be avoided whenever possible.

If it is desired to darken any part, the coating mixture may be prepared and applied by means of a brush to the desired portions and the whole exposed to light when dry. It is then washed in water for about half an hour and dried in the regular way. It is necessary to include the sensitizer in order to secure the same tone as the original deposit.

Registration.—When making multiple prints it is necessary to employ an accurate method of registering the separate printings so that they fall exactly over each other. Many methods have been devised for this purpose and a few of the most generally useful will be described here. A very accurate and convenient method is that devised several years ago by Horsely Hinton for making combination prints. The sensitive paper, which must be larger than the negative, is placed face up on a smooth drawing board and the negative placed with the

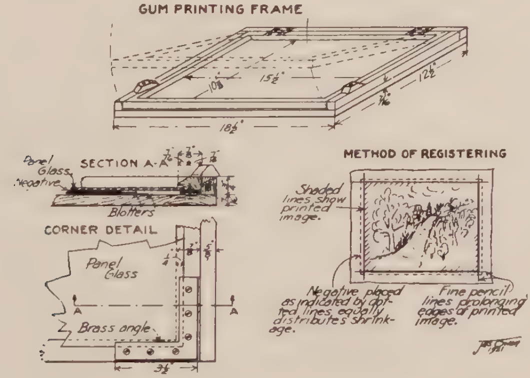
GUM PRINTING FRAME
15½"
10⅛
12½"
18½"
SECTION A-A
Panel Glass
Negative
Blotters
CORNER DETAIL
Panel Glass
A
A
Brass angle
3½
METHOD OF REGISTERING
Shaded lines show printed image.
Negative placed as indicated by dotted lines equally distributes shrinkage.
Fine pencil lines prolonging edges of printed image.

Fig. 191. Owens' Frame for Multiple Printing

emulsion side in contact, when necessary a thick piece of plain glass being placed over the whole to secure perfect contact. On one side of the negative two stout pins are fixed firmly in the board and two similar pins placed against the negative on the contiguous shorter dimension. Registration is secured by replacing the pins in the holes after each printing and forcing the negative up against them.

James Owen in *American Photography,* 1923, p. 416, describes a printing frame designed by him especially for multiple printing. The construction is simple and obvious for the purpose in view, which is to provide a backboard on which to lay the sensitized paper either for the first printing or after one or more previous printings; on the paper is laid the negative, and the glass panel is then clamped down by means of two simple wooden buttons, with minimum chances of disturbing the registered relation between negative and paper.

Registration is accomplished by using the corners of the negative as reference points. When the first printing has been made, clean impressions of the edges of the negative are usually left. With a hard pencil the edge lines are prolonged as shown in the accompanying diagram, before applying the second coating. Whatever shrinkage the print has undergone its first or succeeding development is readily distributed as shown in the diagram. With some hard finished papers there is little or no shrinkage but the pencil lines serve for registering the corners of the negative exactly with the corners of the printed image. The essential point is that a frame of this type is a simple device in which print and negative may be quickly registered and clamped for printing without slipping out of register.

The size of the frame naturally depends upon the largest size of negative to be printed from. It should be several inches larger, all round, however, than the largest negative to be used. Figure 224 will give a general idea of the principle and the details of construction.

Mr. William H. Zerbe uses a frame several sizes larger than the negative with a sheet of plain glass, to this glass he attaches in one corner two strips of glass to form a true square. On the sides of these strips, about where the center of the negative will come, a piece of gummed paper is fixed. Lines are then drawn across in the exact center from side to side and top to bottom as shown in Fig. 192.

The back of the paper is worked off with a T square, either before or after coating, making a line about ¾ to 1 inch at the edges in the center of sides, top and bottom. In this way the marks are square although the paper may not be.

The negative is then placed in position, one corner being forced into the frame made by the two strips of glass. The paper is then placed over the negative and the marks on the paper and the strips gummed on the glass made to coincide. After the first print is developed and recoated, all that is necessary for registering is to make the registration marks coincide again. Should there be any stretching of the paper it will be distributed four ways and minimized.[2]

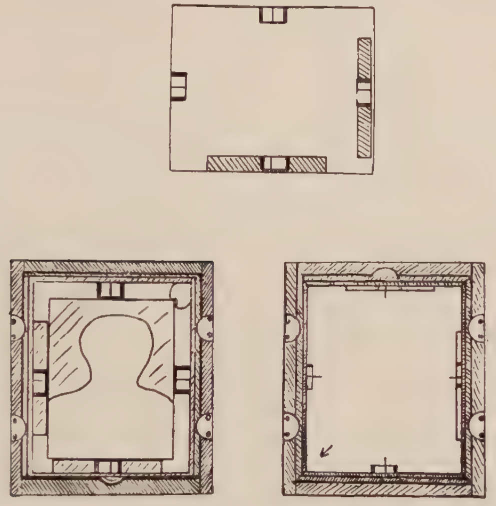

FIG. 192. Zerbe's Method of Registration

Gum-Bromide and Gum-Platinum.—To avoid the difficulties of multiple printing (which is necessary in the ordinary method of gum-bichromate in order to secure an image having the proper depth and gradation) while at the same time preserving the quality of the gum print, many workers have combined the process with bromide or platinum, using a print made by one of the latter as a foundation print to supply the needed depth to the shadows and half tones, over which a gum-pigment image is made to secure richness and quality of image which it alone will yield.

Since the character of the finished print is greatly affected by the depth and contrast of the foundation print, the ultimate end should be carried in mind when making the bromide or platinum print. Generally speaking, the contrast of the foundation print should be rather stronger than usual. The shadows, however, must not be as dark as desired in the finished result, for it must be remembered that their intensity will be increased somewhat by the layer of pigment superimposed over them.

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[2] *American Annual of Photography,* 1923.

The proper depth varies in exactly opposite ratio to the amount of pigment used in the gum coating:—the stronger the gum-pigment coating, the lighter should be the shadows of the foundation print—and *vice versa.* If the intention is to use a gum coating weak in pigment, so as to obtain just a slight glaze of pigmented gum, the foundation print must be almost as dark as the finished result is required, but, on the other hand, a strong pigment image only requires a weak foundation print sufficient to give the additional intensity required by the darker tones of the subject. It is therefore necessary that one have definitely in mind the effect which is desired and proceed to make the foundation print accordingly.

Before exposure the bromide or platinum paper, as the case may be, is placed upon the negative and its position registered by any of the means already considered. It is then exposed and developed in the usual way, to produce an image of the required intensity. When dry the print is ready for the gum-pigment coating. No definite rule can be given for the coating mixture as so much depends upon the strength of the foundation print and on the effect desired. The only way to determine the quantity of pigment to employ in any particular case is to spread some of the mixture upon a waste print of approximately the same character and note the effects. The operations of coating, exposure and development of the gum-pigment image are practically identical with multiple gum-bichromate and need not be repeated.

The Powder Processes.—There is still another series of non-transfer pigment processes based upon the action of light on bichromated colloids. This series comprises those processes which are collectively termed the *powder processes.* In these an image is first formed in bichromated gelatine after which pigment in powder form is dusted over it. The pigment adheres to those portions of the image representing the shadows and which consist of a soluble colloid, while it adheres only with difficulty, or not at all, to those portions which consist of a less soluble or insoluable colloid, and in this way the image is produced. Of the large number of processes of this nature described in the older works, such as Abney's *Instruction in Photography,* practically none have survived. Mr. E. J. Wall, however, has recently described a powder process which would appear to have a more promising future.[3]

The bromide print, which should have been fixed in plain hypo and not in an acid fixing and hardening bath, is transferred directly from the last wash water to the following solution:

Cupric sulphate	28	gr.	5	gm.
Nitric acid	45	min.	6	cc.
Potassium bromide	4	gr.	0.5	gm.
Hydrogen peroxide	1⅗	fl. oz.	100	cc.
Water to make	16	oz.	1000	cc.

which should be used at a temperature of 70° F. (21° C.). The duration of the action ranges from 5–20 minutes, being dependent probably on the emulsion.

For the powdering of the image any inert pigment, black or colored, may be used, but it should be as finely ground as possible, or the results may show an undesirable amount of grain. The powder may be applied either with a very soft brush or by means of a little sieve having a bottom of the finest muslin. Some of the powder is placed in the sieve which is held over the image and tapped with the finger. This method is perhaps preferable when using a pigment containing rather coarse particles.

Resinopigmentype.—Resinopigmentype, a method worked out by Prof. Rudolph Namias, belongs to the same class of printing processes which we have just discussed. It has attracted considerable attention among pictorialists on the continent and Mr. Joseph Petrocelli of New York has produced some very beautiful work by the process.

It is especially adapted to subjects which do not have a high degree of contrast, as, for instance, winter scenes, the effects of fog, rain, etc. On the other hand, it is ill adapted to images requiring vigor and contrast, for it is impossible to obtain absolutely pure whites.

The point of departure of the Resinopigmentype process is in the use of a positive transparency, which may be on glass, film or paper. This may be made from the negative either by contact or enlargement and must not be excessively contrasty.

The paper supplied by Professor Namias is sensitized by immersion of the sheet of paper for three minutes in a 5 per cent solution of potassium or ammonium bichromate and drying in absolute darkness. It is preferable to sensitize in the evening, then the paper will be ready for use the next day. Nevertheless, the positive paper may be kept for one week in winter, or two or three days in summer, but the best results are obtained with the freshly sensitized paper.

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[3] *Amer. Phot.*, 1924, p. 428.

The paper is printed behind the positive in the manner usual with daylight printing papers, and the exposure is continued until there is a faint brown coloration under the transparencies of the positive, with the details of the half-tones lightly visible. Over exposure is to be avoided.

The most simple and effectual method of raising the relief is to leave the print film side down in a bath of cold water for several hours to eliminate the excess of bichromate. After soaking, the sheet of paper is placed in water at 50° C. (122° F.) for from two to five minutes, which produces a distinct image in relief.

If time presses, the print may be swelled quite rapidly by plunging direct in water at 37° C. (98.6° F.), to which ½ per cent of ammonia has been added. After rinsing in cold water the print is ready for powdering.

The excess of moisture on the swollen surface is removed with blotting paper or chiffon, but not with shaggy cotton or wool. One is then ready to begin powdering by means of a soft brush of polecat hair of medium size, dipped in the powder especially prepared for the process. On continually passing the brush over the paper, the image appears and this operation is continued until the image is sufficiently vigorous. When necessary to remove any excess of powder, use a fresh brush.

If the image obtained is deficient in contrast, it indicates that insufficient powder has been applied, and in this event the proof is placed in a tray of cold water to detach all the powder and a higher relief is produced by ammonia water as previously recommended.

The soaking in water advised is often insufficient to remove the last traces of bichromate, especially if the rapid method of swelling already indicated is employed. The yellow stain is easily removed by immersing the print, before swelling, in a 10 per cent solution of sodium bisulphite or a 5 per cent solution of potassium metabisulphite. It is necessary to do this before powdering, because it removes the same when applied to the print.

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ZIMMERMANN—Zimmermann's Method of Gum-Bichromate. Photominiature, 113.

CHAPTER XXIV

THE OIL PROCESSES

Introduction.—Oil and its companion, bromoil, are now two of the most widely used of all pictorial printing mediums. This is due, without doubt, to the enormous flexibility of the process and to the ease with which the artist can alter values of the original negative to secure the particular effect he desires. The photographer has absolute control over his result as any part of the picture may be darkened, lightened, or even omitted at will. No other process offers the same facility to quite the same extent, although gum is a serious rival.

In the oil process, paper is coated with gelatine, sensitized with potassium or ammonium bichromate and allowed to dry in the dark. When dry it is sensitive to light and is exposed under the negative in the same manner as platinotype. When exposure is complete the print is placed in a bath of water in order to eliminate the bichromate stain and to allow the image to swell. In the bath the print gradually takes on a relief which is more pronounced in the strong highlights, since these have been more completely protected from the light and are, therefore, more soluble in water. The print is then removed and inked up with pigment applied by a brush. The shadows, owing to the fact that they have absorbed little or no water, readily take up the ink from the brush, while the highlights only take the ink with difficulty. Thus the image appears under the action of the brush and is gradually worked up to the desired depth by the application of additional pigment. The use of a hard pigment increases contrast, while thinning down the ink with medium causes the ink to adhere more easily and reduces contrast. The effect is also dependent upon the manner in which the brush is handled and this places an added means of control in the hands of the worker.

Materials for the Oil Process.—The materials for the oil process are few in number and comparatively inexpensive. A good negative, one that has been properly exposed and has sufficient contrast to make a good bromide print, should be selected for the first attempts. While an experienced oil printer can secure a fair print from any reasonable negative, the beginner is advised to select a first rate negative as pigmenting will then be easier and the result more likely to be successful. Aside from the negative and the paper, brushes and inks, which will be discussed at some length subsequently, the worker will need a solution of potassium or ammonium bichromate for sensitizing, a supply of blotting paper, pallette knife, several pieces of glass about 5 x 7 and megilip or medium for thinning the inks.

Papers for the Oil Process.—There is no doubt of the fact that a great deal depends upon the selection of a suitable paper. While there are no important differences in any of the papers that are suitable, some workers have better success with some papers than others, owing no doubt to a personal difference in manner of inking and the effect desired. For the beginner, the best advice that can be given is to select one of the papers named and stick to it until he is sure of himself. Then he may try other papers and experiment until he finds if any other suits him better.

The original Rawlings paper is supplied by Messrs. Griffin, of Kingsway (Kemble Street Corner), London, England. It is an admirable paper in every respect and is one of the best papers that the beginner can use. It is made in smooth and rough and in sizes from 3¼ x 4¼ to 16/18. As compared with other papers, the price is rather high.

The Autotype Company of London also issue two papers, No. 1 and No. 2, for the oil process. No. 1 is a smooth white paper; No. 2 a toned paper with a fine grain. It pigments easily and stands vigorous brush work well. The final carbon support for double transfer is also used by some. Double transfer papers which can be advised are the Autotype papers Nos. 76, 77, and 90.

Brushes.—The brushes employed are especially made for the process. They are made from fitch hair and were formerly made only in France but are now also made in England. They are made of short spring hair and the end is cut at an angle.

The quality of the brushes employed has a direct bearing on the finished result and only brushes of the best quality should be purchased even in the beginning. It is useless to try to get along with brushes made for other purposes and, while good brushes are rather expensive, they last a long time if kept in good condition and their purchase is a distinct economy. To begin with, three of these brushes will serve. These three may be Nos. 14, 10 and a small one for detail work. A larger " Prima " brush, which owing to its being made of hog hair is cheaper, may be used for preliminary pigmenting and will be well worth its cost. As the worker progresses, it will be well to purchase additional brushes in order that he may lay down a charged brush and take up a new one when it is desired to apply ink of different consistency to any part of the print. Mr. F. J. Mortimer, who is one of the best authorities on the process, states that the following brushes cover all the requirements of the most advanced worker:

2 No. 14 Stag-foot Fitch brushes
2 No. 10 Stag-foot Fitch brushes
2 No. 7 Stag-foot Fitch brushes
1 No. 5 Stag-foot Fitch brush
1 No. 10 Straight top brush
1 No. 5 Straight top brush

Brushes should be kept in good condition, not only because they are expensive, but because the quality of the work depends, to a large extent, upon their condition. When pigmenting is complete the brushes should be completely cleaned and not allowed to become dry; when this occurs it will be practically impossible to remove the hardened pigment without destroying the good qualities of the brush. Soak a clean rag in gasoline and rub the end of the brush on the rag. This will completely remove any pigment adhering to the ends of the hairs but if the brush has been allowed to become clogged and the pigment is spread up within the brush, it will be necessary to soak the same in gasoline and finally wash out in soap and water until the brush is absolutely free from both pigment and gasoline. Take care not to get the brushes out of shape while cleaning and when they are thoroughly cleaned wrap them in a piece of white paper and place a rubber band around the handle in order to keep the brush in its proper shape.

Pigments.—Pigments are made especially for the process and are almost entirely of English and French manufacture. They are thick, stiff, greasy inks very similar to those used for lithography, and the latter may be used for the oil processes, but on the whole it is better to purchase that made especially for the process. There are several excellent pigments on the market. The "Rawlings" pigments are excellent and Sinclair's "Permanent" inks, as well as the Drem pigments of Dr. Mayer, may also be recommended. The Ault and Wilborg Company of Cincinnati will make ink for the process upon special order, which costs about half of the foreign product.

A large variety of different colors can be obtained but black is recommended for the beginner, as it suits almost any subject.

Sensitizing.—There is no necessity of varying the concentration of the sensitizing solution of bichromate for different classes of negatives, as is the case in carbon printing, for the final result is under complete control in the operation of pigmenting. Therefore, it is better to select a reliable sensitizing formula and make it the standard. Weak or thin negatives will be difficult to handle no matter what sensitizer is employed. The following formula is recommended by Mr. F. J. Mortimer:

Ammonium bichromate	1 oz.
Water	10 oz.

For use take one part of the bichromate stock solution and two parts of methylated spirit. Care should be taken to thoroughly mix the two. The potassium salt cannot be used with methylated spirit as the latter precipitates the salt. Potassium bichromate, however, may be used with acetone in place of methylated spirit in order to secure a quick drying sensitizer and the following formula can be recommended:

1 part of acetone to each part of potassium bichromate (saturated solution).

Many other formulæ are recommended by different workers but there is no particular advantage over those which have been given except that some of them keep longer when mixed ready for use.

The paper may be sensitized either by immersion or brushing. The latter method is better since it is quicker and cleaner but paper so prepared does not keep so well as that coated by immersion and is best used very soon after it is dry, although it will remain in fair condition for twenty-four hours. Paper that has been sensitized by immersion will keep three or four days. Sensitizing may be conducted either in ordinary artificial light or weak daylight but should be removed to a perfectly dark place to dry. No gas should be burned in the rooms used for drying the paper. The paper must be thoroughly dry before use.

To sensitize by immersion, sufficient sensitizing solution is poured in a tray to cover the bottom to a depth of half an inch. The paper is placed with the gelatine side upon the surface of the solution and allowed to remain two or three minutes, removing it at intervals in order to break air bubbles. Drain the paper and hang up to dry. A Blanchard brush is the most convenient and practical brush for sensitizing. This consists of a piece of glass with fluffless flannelette wrapped over one end and secured with a rubber band. Using this brush the paper may be pinned to a board and sensitized in much the same manner as gum-bichromate paper; the operation is much simpler, however.

Exposing.—The operation of printing is similar to any other printing process as P-O-P or Platinotype. The paper is about four times as fast as the former and slightly faster than the latter and care must be taken not to allow actinic light to reach the same in loading the frame or while examining the progress of printing. The image is semi-visible, in this respect closely resembling Platinotype. Printing is continued until detail is visible in the highlights. A few trials will show the proper stage to print. A photometer is not really necessary but may be a help where it is desired to make several prints as nearly alike as possible.

It is advisable that the sheet of sensitized paper be at least an inch larger than the negative, in order that the print may be inked to the edge without danger of getting moisture from the inking pad on the brush.

There is a slight continuing action after exposure and where several prints have to be exposed before pigmenting the prints should be immediately placed in a tray of water in order to stop the continuing action.

After exposure the print is immersed in water to eliminate the bichromate stain and to produce the necessary relief. Paper that has been sensitized by brushing will not take so long to become free of the bichromate as that sensitized by immersion. The water should be changed frequently or running water may be used. From one to two hours will be required to produce the degree of relief necessary for pigmenting. The exact time will depend upon the climatic conditions and the temperature of the water. Warm water will produce a high degree of relief very quickly but there is a danger of its affecting the gelatine and causing the half-tones to be lost. Moderately warm water, say about 75 or 80° F., however, may be used. Demachy has suggested that a very small amount of sodium *bisulphite* be added to the first few washing waters in order to facilitate the quick and thorough removal of the bichromate.

After washing the print may be dried and pigmented at some future time or it may be placed on the inking pad and the operation of pigmenting begun at once. In the former case, it will be necessary to soak the print in water for about an hour in order to raise the relief and get the print in a suitable condition for pigmenting. If it is desired to pigment at once, the print is laid upon the wet pad to be described and the surplus moisture taken off with a blotter or, better, with a ball of silk or flannel.

Pigmenting.—This is the most important stage of the process. Unfortunately, it is very difficult to give any precise information upon this point since it varies for every worker and methods which may be perfectly adapted to one individual may be utterly useless with another. It is an operation in which the worker must develop his own methods and where his own skill and individuality must find the way. Nevertheless, it is hoped that the few particulars which follow will be of assistance to the beginner.

It is necessary to keep the print wet from underneath during pigmenting and for this a pigmenting pad is used. Pads are a commercial article and may be obtained from any of the dealers carrying oil materials or one may be improvised from a sheet of glass and four or five sheets of blotting paper. Soak each sheet of blotting paper in water until thoroughly wet and then place on top of one another upon the glass plate. Upon this spread one or two thicknesses of muslin or cheesecloth. Then remove the print from the wash water and place on top of the pad. With a blotter or piece of silk take off the excess moisture, being careful not to make the surface wholly dry. Only take off the excess water. It will be noticed that the image stands out in relief and the appearance of the print at this stage is a good indication of the way it will take the pigment. The greater the relief the more readily the ink will take.

Squeeze out a very small quantity of pigment on the palette. Only a small quantity is needed, as a piece the size of a pea will do for several 8 x 10 prints. Instead of a palette the glass side of an old negative may be used. Spread the pigment out in a thin layer with the palette knife and tap the brush on the same so as to take up the pigment on the end of the hairs. When the brush has become charged with the pigment, work it around on a clear portion of the glass in order to distribute the pigment evenly. It is well to prepare pigments of two consistencies at the beginning, since it is rare that the same pigment can be used throughout the operation owing to the fact that some parts of the image require a softer pigment in order to make the pigment adhere. Either linseed oil, Robertson's medium or megilip may be used to soften the hard ink. Only a trace of any one of these is necessary to completely change the ink and, therefore, they should be added with caution.

As the image is only faintly visible, a straight gaslight print will be of service in indicating what should be done and if this print has been "worked up" in the same manner as the oil print, then the worker will have a clear and definite idea of the alterations to make in order to secure the results desired.

The proper method of holding the brush is illustrated in Fig. 193. While the manner varies somewhat with the worker, the above may be taken as a safe position to use. The brush must be held lightly and not gripped. Nor should it be held close to the hair. The position is very similar to that adopted by the painter and if one has a friend who is a painter, he can no doubt secure some advice from him on this point.

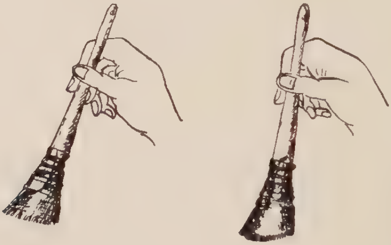

FIG. 193. Proper Position of the Brush in Pigmenting.
(Mortimer and Coulthurst, *The Oil and Bromoil Processes*)

The method in which the brush is handled to apply the pigment also varies greatly as almost every worker has developed individual methods in practice. Some have a pressing, smudging action while others simply dab the brush on the surface. It is difficult to give any precise directions on this point and the worker will develop a distinctive method of his own with practice.

It is well to begin pigmenting with the ink as it comes from the tube and continue until the image is distinct and the shadows well defined, when it may be advisable to change to a softer pigment. It is easy to tell when more pigment is needed for the brush will begin to pick up the pigment instead of depositing it. Use the hard ink as long as possible for it is possible to apply softer ink over the hard if the latter refuses to adhere but hard ink cannot be applied over soft ink.

To lighten any portions which have been over-pigmented the operation known as "hopping" is used. In this the brush is held vertically above the surface and allowed to fall upon the paper. The brush is never dropped from a greater height than about two inches or the gelatine might be punctured and the print destroyed. Wire holders are supplied to hold the brush so that hopping may be carried on without fatigue. The operation should be looked upon as a corrective only and not used unless necessary as far better results are obtained by straight pigmenting to the point desired, but there are cases where it will be necessary to ink over small details and use the hopping action afterward to clear out the highlights so the worker should become familiar with the operation.

It is necessary that the print be kept in a moist condition throughout pigmenting or the pigment will adhere all over. If the side of the print underneath feels dry to the touch the pad should be rewetted and the print may also be placed upon the surface of a tray of water for a few minutes and, finally, again removed to the pad, and pigmenting begun.

Success in oil printing is dependent on two things—understanding and practice. The worker must not be discouraged if his results at first fail to satisfy but must stick it out and he will gradually note improvement in the results. His first endeavors should be directed towards securing a smooth, even application of the pigment and becoming familiar with the results secured with different inks and manner of handling the brush. After he feels that he has mastered the technical principles involved and can make a good straight print with certainty, he may then attempt to make alterations as his artistic taste may direct. Local values, however, should be studied very carefully and alterations should not be made until the worker has satisfied himself that they are advisable. It is not exceedingly hard to master the oil process technically but to master it artistically is an achievement and one deserving of the reward which such masters as Demachy, Mortimer, Job and Puyo have received.

Incorrect Exposure.—In the case of over exposure, the print takes up the pigment too easily and the shadows soon block up and lose their details while the half-tones appear smudged and the highlights take the pigment also and rapidly darken. If the print is much over exposed, it may as well be thrown away, but if only slightly over exposed, the use of a hard ink and hopping may produce a passable result. It is better for the beginner to throw away a print of this nature and make another as all the skill of an advanced worker is required to get a passable print from one which has been incorrectly exposed.

With correct exposure, the shadows take the pigment gradually and the half-tones and highlights keep their proper relations. This shows that the print has been suitably exposed for the pigment in use and all that is necessary is to keep on applying the ink until the desired result has been secured. Success in pigmenting depends greatly upon the exposure and every care should be taken to secure correct exposure in order that pigmenting may be a straightforward and certain operation.

When the print has been under exposed there is difficulty in making the pigment adhere even in the shadows. Prolonged brush action causes the deposit to become granular and thin. This granular appearance is always an indication of either under exposure or the use of too hard an ink. The addition of a small amount of megilip or oil may be sufficient to soften the pigment so that it will adhere. If the first addition is not sufficient more may be added but it is better to use a hard ink than a soft one as the latter does not preserve the contrasts properly but tends to produce the effects of over exposure. Only a very small quantity of oil or megilip is necessary to soften the ink and care should be taken not to make it too soft. As in the case of over exposure, a print which has been very much under exposed is unsuitable and should be thrown away.

Drying and Mounting.—When pigmenting is finished the print may be hung on a line in a dust-free room to dry. It may be placed in a horizontal position for drying but in this position it is more likely to collect dust. The paper and gelatine may require two or three hours to dry but the pigment takes quite a time and it is well to allow at least twenty-four to thirty-six hours for drying. For mounting, it is best to use the dry process but the pigment should be thoroughly dry before mounting or it will come off while in the press. If glue or paste is used, it is best to only tip the corners so that they stick to the mount and not to try and mount the print flat. The print may be rubbed with a soft cloth after the pigment is dry to remove any particles of dust adhering, but so far as possible these should be avoided by drying in a perfectly clean and dustless place. The point of a sharp knife may be used to remove loose hairs, etc., which are embedded in the pigment.

Duvivier's Process.—Monsieur Duvivier in his work *Le Procédé a l'Huile en Photographie* describes a new process of oil printing in which the usual gelatine paper is replaced by one with starch. A thick, unsized paper is coated with starch, sensitized and exposed in the same general way as usual in oil printing. After exposure and development, the print is dried. It is then placed face up upon a pad of wet blotting paper. The paper is able to absorb water from the back, but those portions which represent the shadows and half-tones of the image are protected to varying degrees by the bichromated starch coating and remain dry while the highlights and lighter tones take up water in varying proportions. The highlights thus become moist enough to repel the ink while the shadows being dry take up the ink readily and the print is thus in a similar condition to the swollen gelatine used in the usual oil process. In the case of the starch process, however, the difficulties of pigmenting are lessened owing to independence of the variations in the degree of swelling and consequently the adjustment of the pigments does not require to be as fine, so that the process is much simpler than oil. For full details the original work should be consulted.

The Bromoil Process.—Very similar to the oil process is Bromoil. The bromoil process, in brief, consists in the making of a good bromide print in the ordinary way and bleaching this in a solution which produces an image in insoluble gelatine having the property of taking up pigment from a brush in just the same way as oil printing. Owing to the fact that an ordinary bromide print is used, no daylight is necessary at any stage and as enlarged negatives are not required when an oil print larger than the original negative is desired, the bromoil process is a very popular one among pictorial workers and bids fair to entirely supplant the older oil process.

The Choice of the Paper for the Bromide Print.—While theoretically any bromide paper should be suitable for bromoil, in practice such is not the case. There are considerable differences among various papers in respect to adaptability to bromoil, while there are some few papers which can be used only with difficulty. The qualities of a bromide paper adapted for bromoil as indicated by Professor Namias are:

1. Hard, durable and well-sized paper base.
2. Emulsion rich in silver and gelatine and thickly coated.
3. No hardening substances to be added in manufacture.

It is not possible to use papers the swelling power of which has been lessened by hardening with alum, or other means, in the process of manufacture. The principle of the bromoil process is that a tanning of the gelatine shall take place *differentially* in exact proportion to the opacity of the original silver deposit, so that we get a tanned image in a bichromated colloid. If, however, the emulsion has been hardened in manufacture the gelatine is already tanned and has lost most of its swelling power, so that it is impossible to get the degree of relief necessary for proper pigmenting.

To determine whether a particular brand of bromide paper is suitable for bromoil, Dr. Emil Mayer, in his *Bromoil Printing and Transfer,* suggests that an unexposed sheet of the paper be dipped in water at a temperature of 86° F. (30° C.) and the behavior of the gelatine film observed. If this swells up considerably and becomes slippery and shiny, the paper has the necessary swelling power and can be used for bromoil.

A smooth matt paper is the best adapted for bromoil. Glossy papers are unsuitable, and there is, in many cases, difficulty with the rough surfaces of certain brands of paper. While most of the reputable brands of bromide paper may be used successfully, several manufacturers now supply papers made especially for the bromoil process. These withstand rough treatment better, and being more thickly coated and unhardened, give more relief than ordinary bromide papers (the emulsion of which is nearly always partially hardened in manufacture), and are consequently more easily pigmented. Among such papers available at present, the following may be mentioned: Wellington Bromoil, Vitegas Bromoil, Gevaert Bromoil, and Drem Bromoil Paper.

The Production of the Bromide Print.—It cannot be too strongly emphasized that the production of a bromide print suitable for bromoil is a matter of great importance and one on which the success, or otherwise, of later operations largely depends. In fact, one should not attempt bromoil until he has complete mastery over bromide printing and can make it responsive to his demands. The bromide print to be used for bromoil should be the best which that particular negative will produce. The best prints for bromoil are the result of correct exposure and development for a period slightly less than that required for full depth. To this end the factorial method of development may be used as indicated in the chapter dealing with bromide printing. A lower factor should be used, however, and Dr. J. B. T.

Glover recommends the use of a factor of 5 with the following amidol developer, which is the standard formula of the Kodak Company:[1]

Amidol	26.2 gr.	6 gm.
Sodium sulphite (dry)	110 gr.	25 gm.
Potassium bromide (1 per cent solution)	7 min.	15 cc.
Water	10 oz.	1000 cc.

Practically all developing agents in general use have a more or less pronounced tanning action on gelatine. The use of such developing agents, therefore, has the effect of producing an additional tanning action, not only on the shadows, where it might be desirable in certain cases, but also on the highlights where tanning of any kind is objectionable. The use of a developer with a pronounced tanning action has, in fact, the same effect as general fog in negative making. With emulsions which have been hardened in manufacture the use of tanning developing agents obviously is even more objectionable than in other cases. Accordingly the use of a developing agent without tanning action on the film is desirable. Such agents are amidol (diaminophenol), glycin and the iron developer. While the last named is, with certain precautions, excellently adapted to the development of bromide papers for ordinary purposes it is unsuitable for prints to be used for the bromoil process. Glycin is not especially well adapted to the development of bromide papers as it is slow in action and of the three, amidol is indisputably the best. There is no especial virtue in formulas and that given above will answer any requirement. The worker, however, may use that advised by the manufacturer provided development is regulated properly.

The fixing which follows development is an important operation. A plain bath of 20 per cent hypo should be used. This must be made fresh for each bath of prints and discarded after use. The use of an acid fixing and hardening bath is to be avoided as, owing to its action on gelatine, considerable difficulty is experienced in bleaching and in securing the necessary relief for pigmenting.

Washing should be thorough, as the slightest trace of hypo left in the print will cause trouble in bleaching.

At this point, before leaving the subject of the bromide print, it is well to remark that the print should have a plain white margin of at least half an inch.

Bleaching of the Bromide Print.—As soon as washing is complete the bromide print may be bleached, or it may be dried and kept for bleaching and pigmenting at some future time. It is perhaps preferable, however, to allow the print to dry at this stage. Then when ready for bleaching it can be immersed in water for a few minutes until thoroughly limp.

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[1] *Brit. J. Phot.*, 1921, **68**, 87.

The functions of the bleaching solution are two in number:

(1) It removes the visible silver image and (2) it causes a tanning of the gelatine film corresponding to the silver image that disappears. In place of the original image of metallic silver, there then exists an invisible one of differentially tanned gelatine. Ordinary reducers are therefore unsuitable. They dissolve the silver image but do not possess the property of tanning the gelatine film in the required manner. Dividing bleaching and tanning agents for the bromoil process into the substances they contain we have:

a. Copper sulphate, potassium bromide, potassium bichromate.
b. Copper chloride or sulphate, potassium bromide, chromic acid.
c. Copper chloride, sodium chloride, potassium bichromate.

No reliable methods of testing being available, it is impossible to say that any one of these is better than the other. Bleachers of all three types are used by various noteworthy exponents of the process and so much depends upon a knowledge of the bleacher and its action, and the mode of pigmenting, that it is in manipulation rather than in the type of bleaching solution that the causes of failure should be sought.

Dr. Mayer, the celebrated Austrian expert, gives the following formula for a bleaching solution:

A.	Copper sulphate	¾ oz.	20 gm.
	Water	3½ oz.	100 cc.
B.	Potassium bromide	¾ oz.	20 gm.
	Water	3½ oz.	100 cc.
C.	Potassium bichromate	150 gr.	10 gm.
	Water	3¼ oz.	100 cc.

For use take:

A	2 oz.	60 cc.
B	2 oz.	60 cc.
C	⅔ oz.	20 cc.
Water	15 oz.	450 cc.
Hydrochloric acid (conc.)		15 drops

Raymond E. Crowther advises the following bleaching bath which he claims is entirely without action on plain gelatine but exerts a powerful tanning action in conjunction with the silver image:

Copper sulphate (crystal) 10 per cent solution	170 min.	9.6 cc.
Potassium bromide 10 per cent solution........	130 min.	7.3 cc.
Chromic acid 1 per cent solution..............	45 min.	2.7 cc.
Water to make............................	3½ oz.	100 cc.

This bath should bleach the image in 3 minutes at 60° F. When the temperature is abnormally low, say 40° F., the bath may be used double strength. If the print has not been completely fixed and washed, the bleaching operation will not be successful; it therefore affords a means of indicating the thoroughness of these operations.[2]

Writing in the *British Journal of Photography* on the Bleaching of the Bromoil Print (1924, p. 427) H. J. P. Venn, B.Sc., strongly advises the use of two separate baths for bleaching and tanning. Before bleaching the print is soaked in water for 5 minutes and then drained and transferred to the bleaching bath (No. 1) composed as follows:

Copper sulphate (10 per cent solution)......................	95 parts
Potassium bromide...	5 parts

It is then drained and transferred without rinsing to the tanning bath (No. 2) which consists of

Potassium bromide (10 per cent solution)....................	20 parts
Potassium bichromate (1 per cent solution)..................	10 parts

It is allowed to remain in this bath for 4 minutes, then washed in several changes of water, each of five minutes' duration, and fixed in a 10 per cent solution of hypo for two minutes. After about 15 minutes' washing the print is dried, being again soaked in water before inking up until the desired relief has been reached. This time will vary with the grade of paper. The times of soaking for a few of the more common grades are as follows:

Kodak Royal...........................	45 min. at 75° F.	C. 24°
Barnet CC.............................	30 min. at 65° F.	C. 18°
Wellington Bromoil....................	30 min. at 65° F.	C. 18°

Somewhat longer periods of soaking will do no harm but the ink used will then require to be slightly softer.

To secure a print suitable for pigmenting from a contrasty negative increase the amount of potassium bichromate by using a 5 per cent solution. When used in the two-bath process this does not complicate the process.

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[2] *A. P.*, 1921, p. 446; 1922, p. 2.

Fixing.—In the process of bleaching and tanning a secondary image of silver bromide is formed. This image is light sensitive and, while not visible at the time, will appear upon exposure to light. It is therefore necessary to fix a second time, in order to remove this silver bromide. The fixing bath for this purpose consists of a plain 10 per cent solution of hypo. The usual thorough washing should follow the fixing operation. The print must then be allowed to dry normally.[3]

Producing the Relief.—When ready to begin pigmenting, the print is immersed in water and the gelatine allowed to swell. The degree of swelling is controlled principally by the temperature of the water and, to a lesser extent, by the time of immersion. The higher the temperature of the water in which the print is soaked, the greater the swelling and the more pronounced the relief. With insufficient immersion, or the use of cold water, the degree of swelling will be insufficient and such prints will, when pigmented, have a short scale of gradation with poor tones. The use of excessively warm water, on the other hand, will produce a pronounced relief which, when inked up, may produce a result having greater contrast than is desirable. Between these two extremes of temperature lies an entire series of intermediate stages, which may be employed as occasion demands.

Different papers vary as regards the temperature necessary for producing the best relief. Some are ready for pigmenting after soaking for several minutes in water at ordinary room temperature. Others require as high as 90° F. (32° C.) or more; the general average being about 75–80° F. (24–27° C.). The worker must learn by experience the temperature to use for his particular brand of paper and manner of working, always remembering that it is best to start with a rather low degree of relief, which may be raised quite easily, if required, by soaking in warmer water, while a relief once too high can be reduced only with difficulty. Should soaking in warm water at a temperature of 95° F. (35° C.) be insufficient to produce the desired degree of relief, the print may be immersed in a 1 per cent solution of sodium carbonate as recommended by E. Guttmann. As a rule, however, this method should be used only as the last resort.

Pigmenting.—The relief having been raised to the required stage the print is placed upon the wet pad of blotting paper and the surface moisture carefully removed with a clean, dry, lintless blotter. It is necessary that all the moisture on the surface be removed or the pigment will not adhere evenly.

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[3] According to one method the prints are bleached after development and before fixing. This removes the necessity of the second fixing, but is not so reliable as the method we have described.

Pigmenting is conducted in practically the same manner as with the oil process, but there are a few points which might be mentioned. It is best to begin with a stiff pigment in all cases and only apply the soft ink towards the end when it is desired to finish off the roughness of the gradations. Always have a margin on the original bromide print, otherwise there is a danger of getting the brush wet when attempting to pigment the edges. When the wet brush is transferred to the print it immediately begins to remove the pigment and the work will have to be done over again.

Do not be in a great hurry. Work quickly but with care and do not treat the delicate gelatine surface roughly or it may be destroyed.

Do not be afraid to apply plenty of pigment but do not try to put it all on at once. Smooth it down to an even tint on the palette and take up a little on the brush at the time. When this is exhausted take up more. A smooth, even tone will result if plenty of pigment is used and it is thoroughly worked into the surface. If the pigment is not well worked in, the print will be weak and "gritty" and the tone will be impure.

Beginners usually make the mistake of jumping about from one portion of the print to another. Do not do this. It only makes it more difficult to get an even, smooth result. Work systematically, starting on one side and covering the entire print as you go.

All detail which is to appear in the finished print should be apparent after the first inking. If parts of the image are inked strongly before the desired details appear, it is difficult to ink these later.

Particular care is necessary, especially in the case of large prints, or where a long time is required for inking, to keep the paper stock thoroughly wet. To this end it is well to soak the print in water frequently during pigmenting. A partially dry surface is responsible for many of the troubles met with in pigmenting and if the print is resoaked for 5–10 minutes in water whenever any difficulty is met with in pigmenting much better results will be secured and many of the supposed difficulties of the process will disappear.

Mr. Chas. H. Partington in the *American Annual of Photography* for 1922 adopts what is probably the most satisfactory method of indicating to the beginner in bromoil printing precisely what brush work will accomplish. By the courtesy of Mr. Partington I am able to reproduce the print and accompanying data, which serve to show graphically the effect of variations in pigmenting on the appearance of the image.

In Fig. 194, the section, *A,* has been pigmented with a heavily charged brush and no attempt has been made to change the result. This blocks the shadows and increases the gloss of the highlights producing a soot and whitewash effect. A better result would have been obtained by using less ink and a quicker action of the brush.

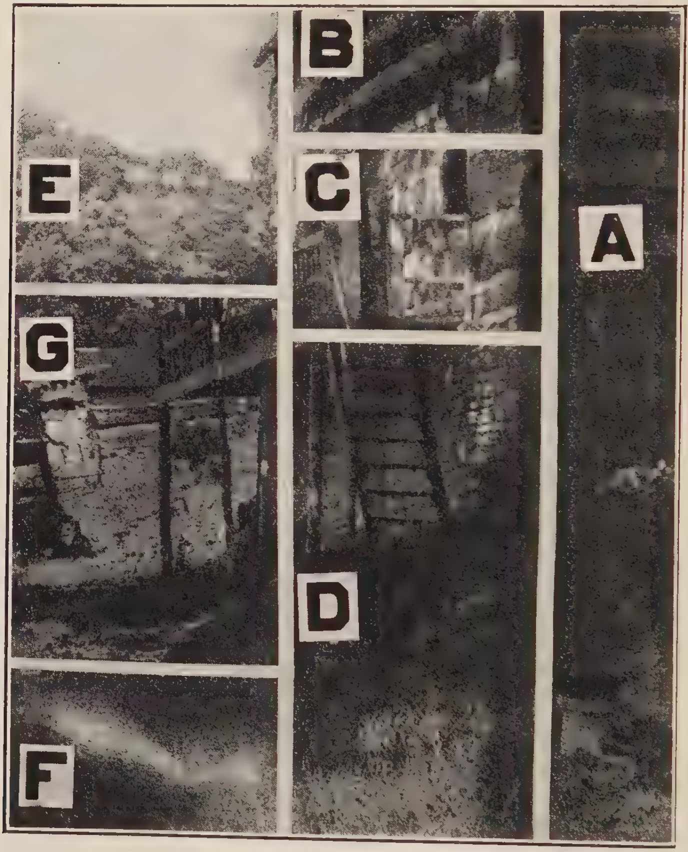

FIG. 194. Results in Pigmenting. (Partington)

At *C* is shown the effect obtained by not having enough ink on the brush. This gives a very soft, flat result.

At *D* ink was applied as at *A* but "hopping" was resorted to to remove the excess ink. The trees in *E* were "hopped" in order to lighten the tones and give the effect of distance.

The portion at *F* shows the surface when first inked and is included for the purpose of showing the effect when the ink is first applied.

At *G*, the print has been inked with a properly charged brush and slightly "hopped" to give additional contract.

Namias Method of Pigmenting.—A very ingenious method of pigmenting is advised by Namias.[4]

A small portion of hard ink is carefully mixed with ten times its weight of finely rectified turpentine. The brush is at once charged with this mxiture and the operation of pigmenting begun as usual. The surface of the print quickly becomes covered all over with a fine coating of ink. Continue the dabbing action of the brush. Gradually the shadows appear to take on ink and gain intensity, while the details and half-tones become clearly separated from the highlights. As the turpentine evaporates, both on the print and on the brush, the ink becomes thicker and thicker and as it increases in consistency it begins to pass from the print to the brush in the highlights, and from the brush to the print in the shadows. Thus in a very short time the image becomes built up to a surprising extent.

The first part of pigmenting complete, a thicker ink is used. Three parts of hard ink and two parts of soft ink are dissolved in 4–5 times its weight of

Rectified turpentine	1 part
Gasoline (pure)	2 parts

This second ink is applied in much the same way as the first but is intended for the lighter tones and must be used considerably harder than the first, or the former will be removed.

Should the final result be unsatisfactory the print may be swabbed with absorbent cotton saturated with benzol. This will remove every trace of the pigment.

The treatment of the finished bromoil after pigmenting is identical with the oil print already described.

Defatting the Finished Bromoil.—After the print is dry it is well to remove the oil which is included in the ink, and which has the effect of giving a slight gloss to the print. The sheen is greater in the shadows than in the highlights especially if a soft ink has been used, as soft inks contain a larger percentage of oil. To many this gloss constitutes an objection, while there is in addition the danger that the ink may in course of time, through oxidation, give rise to colored stains.

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[4] *Brit. J. Phot.*, 1914, **61**, 626.

For removing this oil some solvent such a benzol, carbon tetrachloride, etc., should be used. Owing to the fact that soft ink may be dissolved by carbon tetrachloride, which is a more energetic solvent than benzol, the latter is preferable. It is poured in a dish and the *perfectly dry* print immersed in the liquid for 5–10 minutes.

Bromoil Transfer.—Oil transfer, first introduced by Robert Demachy about 1906, is now one of the most popular printing mediums among advanced pictorialists. Bromoil transfer, a natural development of oil transfer, consists, as its name indicates, in transferring the pigment from the original bromoil to a sheet of plain paper which may be of almost any surface, texture or color. As the greasy pigment on the bromoil lies on top of a more or less tanned and swollen gelatine film, when brought into contact with any uncoated paper and passed between rolls under pressure, it will leave the bromoil print and adhere to the plain paper. The image in this case, then, consists of pigment on a plain paper base. Transfers, accordingly, have a distinctive appearance entirely unlike that of any other printing process, with the exception of photogravure, since in all other processes the image is imbedded in gelatine or in some other colloid, while in these two processes the image lies on a plain, uncoated paper. Added to this is the advantage of being able, by combination transfer, to extend the scale of gradation, and exercise over the finished result a degree of control which is beyond the limits of even the bromoil process, as flexible as this may be in the hands of the expert.

Making a really good transfer is not as simple as might be assumed from an outline of the operation. Familiarity with the bromoil process, even, does not assure the worker of being able to produce acceptable transfers at the start; only by constant experiment and study can one hope to master the process. But the results are such as to amply repay one for the labor involved in mastering the process and one who has become thoroughly familiar with oil or bromoil should not rest satisfied until he has also attempted transfer.

The Bromide Print.—In general bromide papers which are suitable for bromoil are also adapted to bromoil transfer. According to Mr. C. J. Symes, super-coated bromide papers (i.e. papers which have received a double coating in order to render them non-abrasive) yield particularly fine transfers under certain conditions, namely:

(1) The image must be rather stronger than for bromoil; there must be a distinct veiling of the highlights and the print, as a whole, must be a shade darker than if the straight print were intended for exhibition.

(2) Development of the bromide print must be full. If the kodak amidol formula is used the print must be developed to a Watkins factor of at least 16.

(3) The print must be swabbed with cotton wool before inking, if a bleacher of copper chloride, hydrochloric acid and bichromate is used.

(4) Each batch of paper must be tested for the time of soaking, owing to possible variations in the super-coat.[5]

Preparation of the Bromoil.--To obtain a transfer of good quality soft ink must be used in pigmenting the bromoil as it is impossible to transfer hard ink with certainty, owing to the tenacity with which it adheres to the original bromoil. Soft ink, however, cannot be used unless a high relief is obtained or the ink will adhere to the highlights of the bromoil and a print of the proper gradation cannot be obtained. Consequently it is necessary to start with a rather high relief; this fact must be borne in mind when the print is being made ready for pigmenting and the temperature of the water in which the swelling takes place regulated accordingly. The use of a high temperature, however, may cause the gelatine in the highlights to soften to such an extent that it pulls off in pigmenting or in transfer. When this occurs it is well to make use of ammonia as previously described. As the ink is more easily transferred from the highlights than from the shadows, in consequence of the greater relief of the former and the fact that owing to the tanning of the gelatine the pigment in the shadows is more strongly retained than in the highlights, the contrast of the transfer is usually much less than that of the bromoil. In pigmenting, therefore, the bromoil is made considerably more contrasty than would be required were it to be left as it is. Owing to the fact that the transfer of ink in the shadows may not be complete, it is the practice of many workers to considerably over ink such portions in order that the transfer may have the proper depth in the shadows. To reach the same end other workers have recourse to multiple transfer; the first bromoil being inked normally and transferred, then reinked, paying especial attention to the shadows.

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[5] *Brit. J. Phot.*, 1923, **70**, 103.

Dr. Emil Mayer has found that the difficulty of transferring a bromoil to transfer paper without loss of depth in the shadows, due to an incomplete transfer of ink, may be overcome by first passing the transfer through the press with comparatively light pressure, then separating the bromoil and the transfer paper (without shifting their relative position) so as to expose both surfaces to air. Then place the two in contact and run through the press the second time with increased pressure. With this procedure the transfer of ink is almost complete and there is no necessity for over pigmenting of the shadows. or for a second inking. He also finds that there is no advantage in passing the transfer through the press repeatedly with increased pressure, when this procedure is followed, as the transfer of ink takes place immediately and increased pressure only serves to produce an unnecessary strain on the gelatine.[6]

The Transfer Paper.—Theoretically any paper should be suitable for the transfer but in practice there are some marked limitations. Without going into a detailed discussion of the adaptability of various makes of papers, it may be said that only pure *rag* paper is suitable. The commercial water-color and drawing papers of reliable makers are, as a rule, suitable for the transfer, as are the Japanese and Chinese papers, but the very best paper is that manufactured especially for copper-plate printing. In general, however, the worker will not have much difficulty in using reliable makes of drawing papers, such as, for example, the Strathmore papers of the Mittineague Paper Co. which are obtainable from most dealers in art goods.

With very absorbent papers sizing may be necessary, as the pigment sinks into the pores of the paper and the picture has a flat, "sunken in" appearance. For this purpose make up the following solutions:

Arrowroot or rice starch	2 gm.	60 gr.
Water	100 cc.	3 oz.

The arrowroot should be rubbed up with a small quantity of water and added with constant stirring to sufficient boiling water to make a total volume of approximately 100 cc. (3 oz.). This is applied with a Blanchard brush or tuft of absorbent cotton and the paper allowed to dry without heat when it is ready for use.

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[6] *Amer. Phot.*, 1924 (July), p. 410; *Brit. J. Phot.*, 1924, 71, 412.

As a general rule the transfer paper should be used dry. There are some few papers, however, which require to be slightly dampened. For this purpose it is sufficient to thoroughly and evenly dampen two sheets of blotting paper and place the sheet of transfer paper between them and under slight pressure for several minutes. As different papers act differently in transferring, the beginner should stick to one make and surface of paper until he is thoroughly familiar with it. Then he may, if he desires, experiment with other makes and surfaces.

The Transfer Press.—Special presses for transfer are supplied by the Autotype Co. and Sinclair of London and Drem Products of New

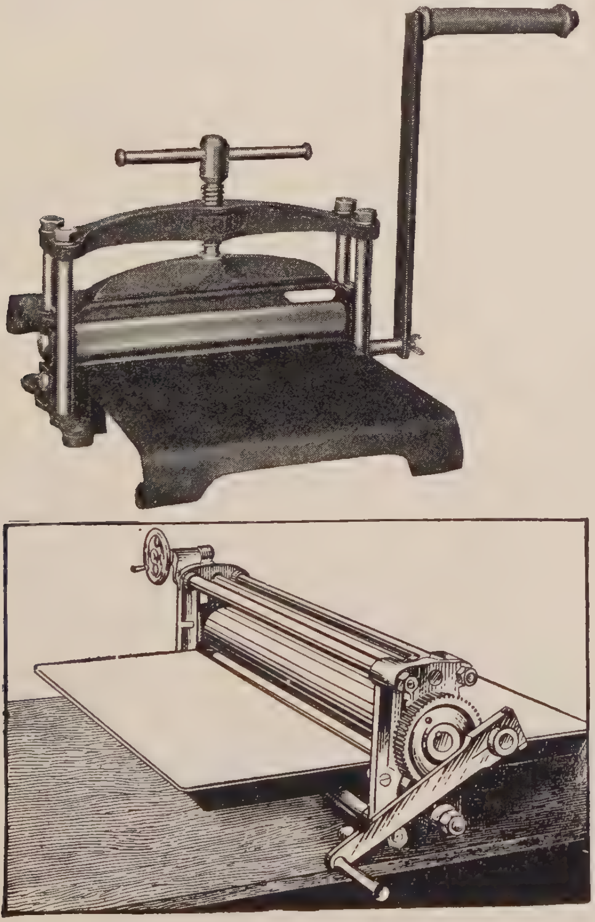

Fig. 195. Transfer Presses

York. These are similar to the presses used by copper plate printers and are expensive. Very good work can be done, however, with one of the old burnishers as used in past days for the glazing of prints or with the better grades of domestic wringers. Whatever the type of press it should satisfactorily fulfill two requirements: (1) the pressure on the rolls must be absolutely even and capable of regulation by the worker and (2) one must be able to examine the condition of the transfer at any time without danger of shifting the position of the bromoil or the transfer.

Perhaps one of the best forms of press for bromoil transfer is that described by K. Prett.[7] This press, which is shown in Fig. 196, is similar to that used by collotype printers. The bromoil in contact with its transfer paper is placed between the two plates of the pressure pad, *P*. The pressure is then adjusted as required by means of the pressure bar, *C*, and the movable pressure pad, *P*, is drawn underneath the pressure bar, *C*, by the windlass, *W*. The whole affair may be made of wood; the two plates composing the movable pressure plate, *P*, being lubricated with a little talc to make them slide regularly. The pressure which can be attained exceeds that of the roller type of press while there is no danger whatever of a displacement of the bromoil and there is less wear on the original bromoil than possible with any other type of press.

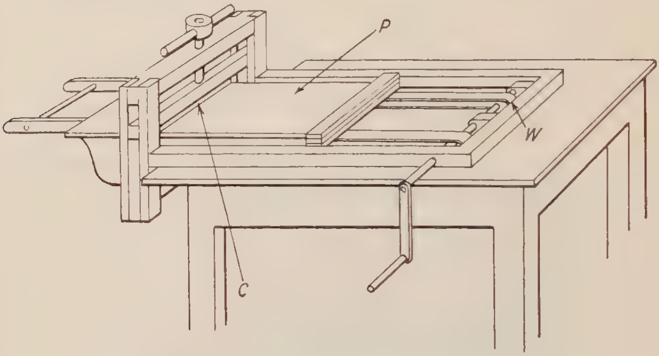

Fig. 196. Prett's Transfer Press

Transferring the Pigment.—As soon as pigmenting is complete the bromoil is ready for the transfer. For this purpose we require, in addition to a suitable press, two sheets of blotting paper, three sheets of thick, hard, glazed pasteboard and a pad of felt—all of which should be at least double the length of the bromoil print. On one of the sheets of pasteboard is placed one of the sheets of blotting paper and on this the pigmented bromoil, face up. Over this is placed the transfer paper, and over this another sheet of blotting paper. These two sheets of blotting paper serve the purpose of absorbing the moisture squeezed from the bromoil print which might otherwise cause trouble. Finally a sheet of pasteboard is placed over the blotting paper, then over this the felt pad and lastly another sheet of pasteboard.

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[7] *Phot. Rund.*, 1923, 1, 5; *Brit. J. Phot.*, 1923, **70**, 300.

The entire pack is now inserted between the rollers and carried through once with a uniform motion and with but slight pressure. The pressure is then increased slightly and the pack carried back through the press in the opposite direction. Then the top of the press pack is removed, the cover of the transfer paper raised and the appearance of the transfer examined. If the transfer of ink is only slight, the press pack is replaced and carried through the press again with increased pressure. Then if the shadows still lack intensity registration marks should be made, the bromoil print removed, resoaked in water and the shadows pigmented after which the bromoil is placed on the transfer paper, its position registered, and again passed through the press. The pressure should not in any case be so great that the rolls can be started only by a decided effort; they must always move easily and smoothly. "Repeated slow passage of the press pack through moderately tightened rollers is always more advantageous than a single passage under very heavy pressure."[8] With heavy pressure there is likewise the danger of destroying the bromoil, as the gelatine film in its swollen condition may adhere to the transfer paper. This trouble, however, is occasionally met with when using some papers with only a moderate amount of pressure. To prevent this, Dr. Mayer suggests that the transfer paper be sprayed with oil of turpentine by means of an atomizer.[9]

After spraying the sheet is allowed to stand for fifteen or twenty minutes in order that the turpentine may evaporate. This is a certain preventative of sticking, but sufficient time must be allowed for the turpentine to evaporate, or muddy, uneven transfers will result.

Zaepernick's Chemical Transfer Method.—In *American Photog-*

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[8] Guttman, *Bromoil Printing and Transfer*, p. 164.

[9] *Brit. J. Phot.*, 1924, 71, 412; *Amer. Phot.*, 1924 (July), p. 410.

raphy, 1924, p. 732, Hans Zaepernick describes a method of bromoil transfer which he terms *chemical transfer.* He says:

> The chemical transfer in its simplest form consists of dampening the paper on to which the bromoil, prepared in the usual way, is to be transferred, not with water, but with a solvent of the ink. The solvents for the greasy inks are: petroleum ether, benzine, benzol, and oil of turpentine. The transfer of the ink from the bromoil to the new surface is effected after solution has taken place by the absorption and adhesive power of the transfer paper. For perfect transfer of the ink, light pressing together of the two surfaces is essential. Even the light pressure obtainable in a printing frame or light rolling with a roller squeegee is enough.
>
> If this method of working is adopted, the bromoil should only be lightly inked. If the inking has been too heavy, the transfer will, as a rule, be too plucky as all the ink goes on to the transfer paper. The degree of hardness or consistency plays but a subordinate part in this process.
>
> If oil of turpentine is used for dampening the paper, black inks show a brownish tinge. With benzine this does not occur.
>
> The advantages of chemical transfer are that since but little pressure is required, it is not necessary to invest in an expensive press and that any kind of paper, even the extremely thin Japanese tissue, may be used.

Rowatt's Process.—In the *Club Photographer* for February 1922, 157, Mr. J. Rowatt describes a method of offset bromoil transfer which he claims removes most of the difficulties of the ordinary bromoil transfer. The pigmented image of the bromoil is transferred to a rubber blanket and from the latter to the final support. The bromoil print accordingly does not require to be reversed as in ordinary bromoil transfer, when unreversed prints are required. For more complete details we must refer the reader to the original.

Multiple Transfer.—Multiple transfer is employed in the same general way and for the same purpose as in gum-bichromate printing—namely, to lengthen the scale of gradation in order that every possible tonal value contained in the negative may be properly rendered. The multiple transfer may be made from one or more bromoils. If only one bromoil print is used, it is first inked up with hard ink, so adjusted to the relief of the print that the shadows alone absorb any considerable quantity of ink, the lighter half-tones and highlights remaining untouched. This corresponds to the shadow coating in gum-bichromate. The pigmented image having been transferred to the transfer paper and means of registration provided in order that it may be placed again in identically the same position, the bromoil is again pigmented, but this time with a soft ink so as to produce a thin, smooth film of ink which reproduces the highlights and half-tones while adding but little, or not at all, to the shadows. This transfer obviously corresponds to the highlight coating in gum-bichromate.

Instead of using the same bromoil print for both transfers, two separate bromoils may be used. This method has the added advantage that different papers may be used for the two bromoil prints, and that the degree of relief of the two prints may be regulated so as to more easily obtain the effect desired in pigmenting.

General Reference Works

Demachy and Puyo—Les Procedes D'Art en Photographie.
Duvivier—Le Procede a L'Huile en Photographie.
Eder—Das Pigmentverfahren, der Gummi-, Oel-, und Bromol-druck und verwandte photographische Kopierfahren mit Chromalzen.
Fuhrmann—Der Oeldruck.
Guttman—Die Selbstbereitung der Bromoldruckfarben.
Guttman—Der Umdruck in Bromoldruckverfahren.
Kuhn—Technik der Lichtbilderei.
Lambert—Oil and Bromoil.
Mayer—Das Bromoldruckverfahren.
Mayer—Bromoil Printing and Transfer. English translation by Fraprie.
Mayer—Manual of Bromoil and Transfer.
Mebes—Der Bromoldruck.
Puyo—Die Oilfarben-kopierprozess.
Puyo—Les Procedes aux encres Grasses.
Sinclair—How to make Oil and Bromoil Prints.
Tilney and Cox—The Art of Pigmenting.
Tilney and Judge—Oil and Bromoil Transfer.
Mortimer and Coulthurst—The Oil and Bromoil Processes.
Stenger—Neuzeitliche photographische Kopierverfahren. (Ozobrom, Bromsilber, Pigmentpaper, Oldruck, Bromoldruck.)
Stenger—Die Kopierverfahren, 1926.
Photo-Miniature No. 106—The Oil and Bromoil Processes.
Photo-Miniature No. 186—Bromoil Prints and Transfers.

CHAPTER XXV

COPYING

Introduction.—Copying is a branch of photography in which many do not succeed, not because of any inherent difficulties the work presents, but because the essentials of the subject which are necessary to success are not thoroughly understood. With the proper apparatus and materials and an understanding of the factors involved, copying is in no ways more difficult than other photographic work and provided the worker knows what he is about he should meet with but little difficulty.

In discussing the subject we will consider first the apparatus advisable, then the optical principles involved and the proper treatment for different classes of copies and finally the photographing of small objects in the studio.

Apparatus for Copying.—In hardly any branch of ordinary photographic work is apparatus so important as in copying and for this reason the question of equipment should be settled before the work is begun. In the first place it is essential that some means be provided whereby the camera may be moved to or from the subject without destroying the parallelism necessary to prevent distortion. Stands for this purpose are made by several firms or a simple arrangement may be made at home by anyone familiar with tools. Figure 197 shows a simple fixture which fills all ordinary requirements and is of simple

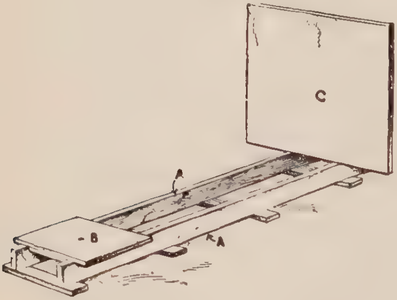

Fig. 197. Copying Stand

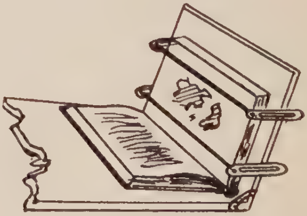

Fig. 198. Book Holder for Copying

construction. The essential parts are the tracks *AA* on which the camera moves to and from the easel *C* which is rigidly fixed at right angles to the base *B* provided for the camera. In cases where an apparatus like this cannot be used, as when photographing a large map or oil painting, a small celluloid T square should be used to determine if the image of the subject on the ground-glass is free from distortion.

For copying from books a holder such as illustrated in Fig. 231 is very convenient. On the whole, however, it is much simpler to use a vertical stand, as it is much easier to keep the page flat when the book is in this position. In fact, a vertical stand is more convenient for nearly all general copying as there is no trouble in attaching the print to the easel and, if daylight be used for illumination, it is easier to secure uniform illumination with the print in this position. Many of the stands on the market may be used vertically as well as horizontally and, as we will see later, the possibility of using the stand in a vertical position is particularly advantageous in another form of copying.

Methods of Illuminating the Print.—The light which illuminates the print to be copied should not only be evenly distributed over the whole print but it should also come from more than one source. The reason for this will be all the more apparent when we have to deal with papers of coarse and irregular texture such as used for drawing purposes. A side lighting from a single concentrated source accentuates the graininess of surface by causing the innumerable projections to cast shadows on the side away from the light. At the same time the projections themselves receive the direct illumination on one side and therefore we have a highly lighted spot in immediate contact with a deep shadow so that the irregularity in the surface of the paper is made far more noticeable than is actually the case and the copy shows a "graininess" which is almost inconceivable when the original is examined visually in a good light.

When copying by daylight it is very difficult to secure uniform illumination and prevent the appearance of an undesirable amount of "graininess." All papers which do not have a glazed surface may be copied in the position shown in *a* of Fig. 199. For glazed prints this position is unsuitable, as the highly glazed surface reflects light into the camera and obscures the image. In such cases, and also in the case of some matt papers which have a "velvet" or enamelled surface, the relation between the print and the light source should be that shown in *b* of the same figure. The presence of reflections can usually be determined from the ground-glass but an infallible rule is to remove the ground-glass and the lens and examine the print from the back of the camera at various angles.

The constant fluctuation in the strength of daylight and the difficulty of securing even illumination make artificial illumination especially desirable. For several years the writer used with complete success the arrangement illustrated in Fig. 200. The interior of the box which encloses the mazda lamps is painted with white enamel to increase the reflecting power and the bulbs are placed back from the circular opening so that no stray light can reach the camera even when very close to the copy. Frosted light bulbs were found to give better illumination with less tendency to reflection and glare than plain bulbs. While somewhat elaborate this outfit is easily constructed and fully repays its expense where a considerable amount of copying must be done, for the circular system of lighting is the most effectual way of avoiding "graininess" that the writer has been able to find. Two mercury vapor tubes, one on each side of the copy, make a satisfactory light but the initial expense is higher. Two large mazda lights, one on each side of the copy, are sufficient when dealing with small copies but fail with very large originals and it is also difficult at times to avoid reflections.

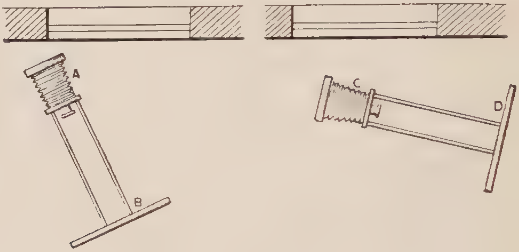

Fig. 199. Illumination of the Copy Using Daylight

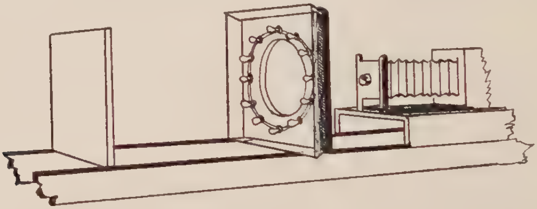

Fig. 200. Copying Apparatus for Artificial Light
(Rose, *The Commercial Photographer*)

Copying Cameras.—For copying the worker has the choice of the instruments made especially for the purpose or the use of view or other types of plate cameras. Regular copying cameras have a long bellows, a central compartment for lenses and quite often a frame of kits at one end for negatives which are to be reduced to lantern slides. When necessary the lens board may be moved from the central partition, where it is placed when making lantern slides, and substituted for the frame of kits in order to obtain greater bellows capacity. Cameras of this type are made by a number of firms and reference to the catalogs of large dealers will show what may be expected in a camera of this type.

Long bellows view cameras which focus from the rear are very satisfactory for copying: in fact in one respect they are actually more convenient than those made especially for the purpose. Copying cameras are seldom fitted with a rising and falling front, but this feature is very convenient at times as it enables the image to be properly adjusted on the ground-glass without the rather laborious operation of removing the print from the easel and replacing it in what is estimated to be the correct position. The swing back fitted to view cameras is also useful at times, enabling distortion in the copy to be corrected. At all other times it should be securely locked in the perpendicular position so that it is parallel with the easel.

Copying with hand cameras having short bellows is possible only when supplementary lenses are used. These, while useful in such cases, cannot be recommended as they affect the definition of the objective to which they are applied.

The Objective for Copying.—Difficult copying demands high-grade objectives. While very good copies can be made with rapid rectilinear lenses these have a falling off in definition towards the margins in addition to astigmatism, both of which are only partially remedied by stopping down. The anastigmat with its flat field and its high freedom from all kinds of aberration gives critical definition and needs but little stopping down, so that for all work which demands utmost sharpness they are far superior to other types of lenses. Lenses well corrected for astigmatism and curvature of field may still have zonal errors or residual spherical aberration. Zonal aberrations detract from the crispness of definition and reduce the limit of sharpness to which one can work. Coma is also a serious disadvantage to a lens used for copying as it gives negatives having a flat, fogged appearance which is sometimes mistaken for errors in exposure or development.

Lenses of medium aperture are superior in these respects to those of large aperture, even though both be used at the same aperture, owing to superior correction for zonal aberration. Unquestionably the best lens for all classes of copying is the process anastigmat, such as the Cooke Series V, *F*/8, Goerz Gotar, *F*/8, Gundlach process *F*/9, Velostigmat process *F*/8, etc., but anastigmats of the type represented by the Dagor, Protar, Turner-Reich, and Tessar 11B, *F*/6.3, are satisfactory for all but the most critical line work.

While the use of a short focus lens means a saving of bellows extension and allows the camera to be closer to the copy for a given degree of reduction or enlargement, it has the disadvantage that the front of the camera may, in certain cases, interfere with the lighting of the subject while at the same time the danger from reflections is greater owing to the larger angle subtended. In general it is well to choose a lens having a focal length equal to, or slightly greater than, the diagonal of the largest plate.

Focusing.—For accurate focusing a fine-grained screen is needed. Much may be done to improve matters by simply applying vaseline to the ground-glass already in the camera but a much better result can be secured by replacing the ground-glass with a specially made screen. A very suitable grainless screen can be made at home at a very small expense. Take a fast plate (unexposed) and develop from fifteen to twenty minutes in a non-staining developer such as amidol or M–Q without a restrainer so as to secure a slight general fog. Rinse and transfer to the following solution:

Potassium bichromate..........................	10 gr.	25 gm.
Hydrochloric acid (conc.)......................	10 min.	25 cc.
Water	1 oz.	1000 cc.

After several minutes' immersion in this, remove and rinse briefly in running water, then fix, wash and dry in the ordinary way. A screen prepared in this manner is denser than one of ordinary ground-glass but shows far more detail owing to its freedom from coarse grain. When dry it is well to rule the screen with vertical and horizontal lines ½ inch apart to assist in determining the size of the copy directly without measurement and to indicate the presence of distortion. When this is done, the screen may be coated with negative varnish to protect it from atmospheric action.

For obtaining critical focus a magnifier must be used. The parallax focusing method, or the use of the Le Clerc diaphragm, in conjunction with a focusing magnifier affords the simplest and most satisfactory method of obtaining the exact focus.

To use the former method proceed as follows:

Remove the gelatine coating of the prepared focusing screen from a small portion about an inch in diameter at the center of the screen. On this clear space glue a piece of tinfoil with a sharp edge. A magnifier is adjusted to sharp focus over the tinfoil and may be permanently affixed in this position. As the eye moves sideways in observing the image an apparent displacement occurs. When critical focus is secured there is no apparent displacement and the image and the sharp edge of tinfoil lie in the same plane.

Clerc's method may be used only when the lens is fitted with removable diaphragms, generally termed Waterhouse stops. As practically all process anastigmats are fitted with removable diaphragms this method becomes very convenient when such lenses are used. To produce the Clerc focusing diaphragm lay off on thin metal a circle equal to the diameter of the inside of your lens barrel. Inside of this circle, lay off a concentric circle equal to the diameter of the largest diaphragm of the lens. Draw a diameter of the inside circle and divide into four equal parts, and at the two points between the center and the circumference of the circle draw perpendiculars to the diaphragm until they cut the circumference of the inner circle. Then cut out the segments and blacken the metal with dead black, matt paint. When focusing with the diaphragm in place there will be a double image but when critical focus is obtained the images unite and form a single distinct image. Remove, insert proper stop, and expose.

Copying to Scale.—Assuming that the exact focal length and the position of the nodal points are known, the worker can enlarge or reduce to scale simply by a graduated scale applied to the camera and the stand. The conjugate distances for various degrees of enlarging or reducing and for lenses the focal length of which varies from 3 to 12 inches are given in the following table. When copying on an enlarged scale the distance from the subject to the lens is less than that from the lens to the plate while when copying on a reduced scale the reverse is the case.

Where the positions of the nodal planes are unknown, the following method worked out by Mr. D. Charles[1] may be employed:

The first requirement is that the ground-glass focusing screen should allow of horizontal movement in its frame over a small distance

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[1] *Brit. J. Phot.*, 1919, 66, 736.

Distances when Enlarging and Reducing

Focus of Lens, Inches	Times of Enlargement and Reduction							
	1 Inch	2 Inches	3 Inches	4 Inches	5 Inches	6 Inches	7 Inches	8 Inches
3	6 6	9 $4\frac{1}{2}$	12 4	15 $3\frac{3}{4}$	18 $3\frac{3}{5}$	21 $3\frac{1}{2}$	24 $3\frac{3}{7}$	27 $3\frac{3}{8}$
$3\frac{1}{2}$	7 7	$10\frac{1}{2}$ $5\frac{1}{4}$	14 $4\frac{2}{3}$	$17\frac{1}{2}$ $4\frac{3}{8}$	21 $4\frac{1}{5}$	$24\frac{1}{2}$ $4\frac{1}{12}$	28 4	$31\frac{1}{2}$ $3\frac{15}{16}$
4	8 8	12 6	16 $5\frac{1}{3}$	20 5	24 $4\frac{4}{5}$	28 $4\frac{2}{3}$	32 $4\frac{4}{7}$	36 $4\frac{1}{2}$
$4\frac{1}{2}$	9 9	$13\frac{1}{2}$ $6\frac{3}{4}$	18 6	$22\frac{1}{2}$ $5\frac{5}{8}$	27 $5\frac{2}{5}$	$31\frac{1}{2}$ $5\frac{1}{4}$	36 $5\frac{1}{7}$	$40\frac{1}{2}$ $5\frac{1}{16}$
5	10 10	15 $7\frac{1}{2}$	20 $6\frac{2}{3}$	25 $6\frac{1}{4}$	30 6	35 $5\frac{5}{6}$	40 $5\frac{5}{7}$	45 $5\frac{5}{8}$
$5\frac{1}{2}$	11 11	$16\frac{1}{2}$ $8\frac{1}{4}$	22 $7\frac{1}{3}$	$27\frac{1}{2}$ $6\frac{7}{8}$	33 $6\frac{3}{5}$	$38\frac{1}{2}$ $6\frac{5}{12}$	44 $6\frac{2}{7}$	$49\frac{1}{2}$ $6\frac{3}{16}$
6	12 12	18 9	24 8	30 $7\frac{1}{2}$	36 $7\frac{1}{5}$	42 7	48 $6\frac{6}{7}$	54 $6\frac{3}{4}$
7	14 14	21 $10\frac{1}{2}$	28 $9\frac{1}{3}$	35 $8\frac{3}{4}$	42 $8\frac{2}{5}$	49 $8\frac{1}{6}$	56 8	63 $7\frac{7}{8}$
8	16 16	24 12	32 $10\frac{2}{3}$	40 10	48 $9\frac{3}{5}$	56 $9\frac{1}{3}$	64 $9\frac{1}{7}$	72 9
9	18 18	27 $13\frac{1}{2}$	36 12	45 $11\frac{1}{4}$	54 $10\frac{4}{5}$	63 $10\frac{1}{2}$	72 $10\frac{2}{7}$	81 $10\frac{1}{8}$
10	20 20	30 15	40 $13\frac{1}{3}$	50 $12\frac{1}{2}$	60 12	70 $11\frac{2}{3}$	80 $11\frac{3}{7}$	90 $11\frac{1}{4}$
11	22 22	33 $16\frac{1}{2}$	44 $14\frac{2}{3}$	55 $13\frac{3}{4}$	66 $13\frac{1}{5}$	77 $12\frac{5}{6}$	88 $12\frac{4}{7}$	99 $12\frac{3}{8}$
12	24 24	36 18	48 16	60 15	72 $14\frac{2}{5}$	84 14	96 $13\frac{5}{7}$	108 $13\frac{1}{2}$

The table is used as follows: Knowing the focal length of the lens to be used and the degree of (linear) enlargement or reduction, look up the figure for enlargement or reduction in the upper horizontal row, and carry the eye down the column below it until it reaches the horizontal line of figures opposite the focal length of lens in the left-hand column.

When *enlarging*, the greater of the two distances where the two lines join is the distance from lens to the sensitive paper or plate. The lesser is the distance from lens to negative, or picture being enlarged direct in camera.

When *reducing*, the distances are *vice-versa:* the greater is the distance from lens to original, the smaller from lens to sensitive plate. (*British Journal of Photography.*)

of ¼ to ½ inch, as may easily be done by cutting a strip of this width off one end of the focusing screen.

A pair of fine lines is then drawn on the focusing screen exactly vertical and two inches apart. The left line should be in the center of the ground-glass and the other two inches to the right of it.

On the copying easel an accurately graduated scale is fixed: a paper scale may be glued to the surface of the easel or a wooden or metal scale set in flush with the surface. A vertical line is drawn on the easel close to the center, so that its image will coincide with the central line on the focusing screen. The scale should be fixed about halfway up the easel at right angles to the central line, with its zero on the line and the graduations lying to the left and upside down.

It is a very simple and rapid operation to slide the ground-glass so that the left hand falls on the zero of the image scale and to note the figure cut by the right-hand line. Thus it is possible to measure instantly the image of the rule by the two-inch column on the ground-glass and by focusing and movement of the camera get any desired degree of reduction or enlargement.

Where it is required to copy subjects to exact size, or to a certain degree of reduction, at frequent intervals it is convenient to mark on the camera and the stand the positions occupied so that focusing may be avoided in the future.

Exposures in Copying.—Five things determine the time of exposure in copying:

1. The strength of the light illuminating the copy.
2. The character of the original to be copied.
3. The speed of the plate used.
4. The actual aperture of the lens.
5. The effective aperture of the lens for the degree of reduction or enlargement being made.

The strength of the light illuminating the copy is constant when artificial light is used and may be determined with sufficient accuracy for all practical purposes by a few trial exposures. When copying by daylight an actinometer should be used.

The second factor is the one giving the most trouble since it follows no definite law and does not permit of measurement conveniently. Only experience can show what allowances must be made for different types of originals although the following table may be of some assistance in this respect.

Original	Relative time	Fraction of the total Watkins meter time
Matt or semi-matt bromide prints, platinums, pencil or ink sketches, steel or wood engraving	1	1/30
Glossy purple P-O-P contrasty bromide prints, black carbon, black photogravure	2	1/16
Etchings in brown, sepia-toned bromides, red or green carbons	4	1/8
Contrasty sepia and red prints, gum bromoil and tissue prints	8	1/4

The type of plate used depends to a certain extent upon the class of subject: thus for line work in pure black and white a process plate must be used; for colored subjects an orthochromatic or panchromatic plate is required while medium speed, non-color-sensitive plates are satisfactory for photographs and like subjects in monochrome. This matter will be discussed more fully when we come to deal with the handling of these various classes of subjects.

With a suitable lens there is no necessity for the use of a very small diaphragm provided focusing has been properly done. Larger apertures tend to produce more brilliant negatives and lessen the danger of unsharpness due to vibration during exposure. If the lens is at all suited to the purpose there should be no need whatsoever for the use of a smaller diaphragm than *F*/16.

The values of the various diaphragms, however, are not constant as in general work but vary considerably with the degree of reduction or enlargement. Thus when copying full size the distance from the nodal plane to the plate is twice as great as the focal length of the lens: hence under these conditions the actual value of the stop has increased four times so that *F*/8 has become *F*/16, *F*/11.3 has become *F*/22, etc. When copying on an enlarged scale the increase is much greater. By working with a certain definite diaphragm the relative exposure for copying or reducing may be calculated from the following table provided the correct exposure for the same class of subject and the same plate is known for a given degree of reduction.

Provided it is possible to illuminate the copying easel with lamps of sufficient brilliance to enable them to be retained at a fixed distance for all originals regardless of size, exposures in copying may be calculated quite simply by the method described by Mr. D. Charles in the *British Journal of Photography*.[2]

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[2] *Brit. J. Phot.*, 1922, **69**, 709.

RELATIVE EXPOSURES WHEN COPYING OR REDUCING

New Scales of Reduction	Scale of Reduction for which Exposure is Known											
	1	3/4	2/3	1/2	1/3	1/4	1/5	1/6	1/8	1/10	1/20	1/30
1	1	1 1/4	1 1/2	1 3/4	2 1/4	2 1/2	3	3	3	3 1/2	3 1/2	3 1/2
3/4	3/4	1	1 1/10	1 1/4	1 3/4	2	2	2 1/4	2 1/2	2 1/2	3	3
2/3	3/4	7/8	1	1 1/4	1 1/2	1 3/4	2	2	2 1/4	2 1/4	2 1/2	2 1/2
1/2	3/5	3/4	4/5	1	1 1/4	1 1/2	1 1/2	1 3/4	2	2	2	2
1/3	2/5	3/5	2/3	4/5	1	1 1/6	1 1/4	1 1/4	1 1/2	1 1/2	1 1/2	1 3/4
1/4	2/5	1/2	3/5	3/4	7/8	1	1	1 1/8	1 1/4	1 1/4	1 1/2	1 1/2
1/5	2/5	1/2	1/2	2/3	4/5	1	1	1	1 1/6	1 1/8	1 1/4	1 1/4
1/6	1/3	2/5	1/2	2/3	3/4	7/8	1	1	1	1 1/8	1 1/5	1 1/4
1/8	1/3	2/5	2/5	3/5	3/4	4/5	7/8	1	1	1	1 1/10	1 1/8
1/10	1/3	2/5	2/5	1/2	2/3	3/4	4/5	7/8	1	1	1	1 1/9
1/20	2/7	2/5	2/5	1/2	2/3	3/4	4/5	7/8	1	1	1	1
1/30	1/4	3/8	2/5	1/2	3/5	3/4	3/4	7/8	7/8	7/8	1	1

To use this table find in the top horizontal line the scale of reduction for which exposure is known. Under this scale the relative time of exposure for different degrees of reduction will be found opposite the new scales of reduction marked in first vertical column.

The power and position of the lamps having been standardized at the start, a lens is placed on the camera and the diaphragm adjusted so as to be exactly one inch in diameter. This for an eight-inch lens would be *F*/8, for a lens of eleven inches focal length *F*/11, etc. The camera is then extended so that the distance from the stop to the plate is sixteen inches and the whole camera moved back and forth until some matter on the easel becomes critically sharp. A print is then pinned up and a plate exposed in steps, developed and the correct exposure noted.

A sheet of paper is then inscribed with the ordinary apertures from *F*/6 to *F*/45 in a column. Opposite *F*/16 is written the exposure arrived at by the test just described. (It will be evident upon consideration of the conditions under which the test was made that since the lens opening of one inch is one sixteenth of the bellows extension, the effective aperture, or the actual working speed, of the lens is *F*/16 regardless of what the aperture marked on the lens mount may be.) Opposite each other diaphragm is written the proportionate exposure following the usual rule.

This procedure is then repeated for a line subject using a process plate and for any other particular class of work which requires distinct treatment, and the corresponding exposures marked against each diaphragm.

A scale is then affixed to the camera so that zero point coincides with the diaphragm of the lens. Obviously, the actual extension of the camera can be determined by observing the figure against which the ground-glass stands. From what has been said before it will now be evident that the extension indicates the value of the stop without any calculation whatsoever. Thus if the extension is eight inches the exposure would be read off opposite *F*/8, if 22 inches opposite *F*/22, etc. If for any reason it is necessary to use a smaller diaphragm the proper exposure may be determined by the usual rules governing the exposures of different diaphragms.

The Copying of Subjects in Pure Black and White.—Having become familiar with the fundamental principles underlying all copying and applicable to subjects of all classes we will consider in some detail the proper methods of handling each class of copy in order to obtain the best results.

Subjects in black and white embrace an extensive and varied field which includes charts, graphs, maps, pen and ink and pencil sketches, wood and steel engravings, etchings and half-tone reproductions. The photography of such subjects, while quite simple in itself, demands precise painstaking attention to every detail if the best results are to be obtained.

While the subject of lenses has already received attention, it may be well to remark at this point that in dealing with line work the best corrected objective is none too good; especially is this the case when dealing with subjects containing very fine detail or when the degree of reduction is considerable. In such cases the absence of zonal abberations and coma is particularly desirable and the process anastigmat is well worth its additional cost where work of this type must be done.

The plates required for handling this class of copy are known as Contrast, Process or Photo-Mechanical plates and are made to give a very high degree of contrast. Wet collodion is still unsurpassed for line work but its use is beyond the capabilities of most workers, but with care all that can be done with collodion can also be done with gelatine although it must be admitted that a satisfactory result from difficult originals is more difficult to secure with gelatine than with collodion. Rapid plates as used for general work cannot be used for this purpose as they do not have a sufficiently fine grain and are unable to give the great density combined with absolutely clear lines which is required for this class of copy. Plates of the process type suitable for line work are all comparatively slow and range in speed from about Watkins 15 to Watkins 45 but work very free from fog and readily give great contrast and density. Typical plates of this class are Cramer Contrast, Seed Process, Eastman Process film, Imperial Process, Wellington Ortho Process, Ilford Process and Half-Tone, Barnet Process and Gevaert Process.

Development of Process Plates.—The development of process plates is best conducted by inspection using a concentrated hydrochinon or glycin developer. The following is considered the best formula for obtaining the maximum contrast:

A.	Sodium bisulphite	375 gr.	25 gm.
	Hydrochinon	375 gr.	25 gm.
	Potassium bromide	375 gr.	25 gm.
	Water to make	32 oz.	1000 cc.
B.	Caustic soda	$1\frac{1}{2}$ oz.	45 gm.
	Water to make	32 oz.	1000 cc.

For use take equal parts of *A* and *B*. The developer will not keep when mixed and a separate batch should be used for each plate. Another formula which has good keeping qualities and gives good contrast is as follows:

Hydrochinon	130 gr.	15 gm.
Sodium sulphite (dry)	3 oz.	150 gm.
Formaline	3 dr.	20 cc.
Water to make	20 oz.	1000 cc.

This is one of the few cases in photography in which the author prefers development by inspection to the time and temperature or factorial methods. For one thing, a comparatively bright light may be used with safety so that there is no difficulty in judging the appearance of the negative. As process plates fix back considerably, development must be carried just as far as possible without causing the delicate lines to veil over. A slight veiling, noticeable towards the close of development, may be disregarded, as it will disappear in the fixing bath. If development is carried as far as possible without producing fog, the density will be all that is desired, unless exposure has been insufficient. If the exposure has been insufficient the negative will lack density when removed from the fixing bath, even though the density appeared to be sufficient when development was concluded. On the other hand should the lines begin to veil over in the early stages of development before the requisite density is obtained, over exposure is indicated. In fact, exposure to suit the original is the key to the whole problem, provided the proper plate and developer are used and development is carried to the limit.

Except with weak originals, or through faulty exposure or development, intensification will not be required. When intensification is necessary Monkhoven's silver-cyanide method, lead or copper are suitable for the purpose.

For the print glossy papers are generally used, especially if there is an abundance of small detail. It may be noted that a hard, vigorous paper gives a cleaner-cut black line than the normal or soft varieties.

Copying Photographs or Like Subjects in Monochrome.—Here the object is to reproduce the various tones of the original as correctly as possible. A slight loss is inevitable, particularly at the ends of the scale of gradation, but if the copy is well made the loss should be small and practically indistinguishable. Especial care must be taken to minimize the grain of the original, particularly if the surface is matt or rough. The apparatus described earlier in this chapter will be of great assistance in this respect. Under exposure and forced development, or the use of a contrast working plate, accentuate any tendency to "graininess" and in such cases it is well to expose fully and shorten the time of development somewhat. When very contrasty originals must be copied the use of an ultra rapid plate will assist materially in toning down the extremes of contrast, but for general work high speed plates are not to be advised and better results will be secured by the use of comparatively slow plates ranging from Watkins 50 to Watkins 150. Plates of this character, made especially for this class of copying, are made by practically all manufacturers. A great deal depends upon the exposure and only experience can show what is required in this respect. A careful record of all experiments and the results secured will assist materially in estimating exposures as will standardization of all controllable factors along the lines which have already been indicated.

Development must be conducted with judgment, and cannot well be made uniform for all subjects. The strong contrasts of some prints, particularly those of a non-actinic color, require to be softened, while flat bluish-black originals should be developed further in order to secure sufficient contrast. In many cases, such alterations can be made by judicious choice of the grade of paper in printing, but at times intensification or reduction may be necessary to secure the proper contrast.

The Photography of Colored Objects.—In dealing with subjects of this class orthochromatic methods are necessary. The subject of plates and filters and their action has been treated in a former chapter so that at this point we will mention only some practical points connected with the photography of colored objects and for further information the student is referred to Mees, *Photography of Colored Objects.*

In general, it may be said that the panchromatic plate is preferable to orthochromatic for all subjects involving color. If desensitizers, or time and temperature methods of development, are used they may be handled with no more difficulty than attends the manipulation of other plates, while their enhanced color sensitiveness to all colors, which allows of shorter exposures for the same degree of color correction, their red sensitiveness and the fact that they enable one to standardize the matter of plates are all important points in their favor.

While in ordinary work, where the subject is at a considerable distance from the lens, the shift in the plane of sharp focus due to the use of a filter is comparatively small and may in many cases be ignored, when copying the matter becomes of considerable importance and filters of the finest optical properties become imperative. Filters supplied for ordinary photographic work are cemented in specially selected glass and are sufficiently near to a plane surface and parallel on both sides not to affect the definition of a lens when used for distant objects. But, whereas the rays from distant objects are practically parallel, those from near objects, as in copying, are quite divergent and if the filter is not both plane and parallel, or in other words is wedge-shaped, it will have the effect of a prism and destroy the finer corrections of the objective with which it is used. The longer the focal length of the objective the more accurate the filter must be in these respects. A filter which would pass muster with a six-inch lens might be practically useless for one of twelve inches focal length. For critical copying from colored objects the filters should be cemented in optical flats which are polished and tested with the same accuracy as the highest grade lenses. Gelatine filters are quite satisfactory but it is hard to keep them clean. The filter may be placed either in front of or behind the lens; the latter is the best position as there is less danger of flare, or flare spot, when the filter is behind rather than before the lens.

For photographing paintings, water color work and crayon a panchromatic plate is necessary. The K_3 or fully correcting filter advised by the manufacturer of the particular brand of plates employed is required for nearly all subjects as usually it is desired to give an exact color rendering of the original. There are cases, however, where it is necessary to overcorrect some color at the expense of another and for this purpose a contrast filter is necessary. This should always be done with caution, however, and whenever possible orthochromatic methods should not be departed from.

Reflections from the surface of paintings are very hard to avoid as they are different from those from a flat surface. The light is reflected from the irregularities in the surface where the paint has been laid on thick and not from one definite plane as is the case with photographs, etc. Placing the painting at a considerable distance from the source of light and cutting out all bright objects in front are about the only methods of avoiding these reflections. The angle at which the light strikes the surface is important but the best angle can only be found by trial and error for each particular subject. Tilting the picture forward is often of advantage; the swing back being used to correct the attendant distortion. Daylight is the best light for copying paintings; artificial light never seems to give quite the proper effect artistically. The exposure varies with the character of the picture; a dark old Master requires very much more time than one of the late productions of the Japanese school. There is a tendency for photographs of paintings to have too much contrast and to counteract this tendency a full exposure should be given and the usual time of development shortened somewhat. Only experience can teach the worker how to handle subjects of this very difficult class.

Silver prints toned sepia, gum and oil prints and transfers all require much the same treatment as paintings unless they are in black or blue-black. If a sepia-toned silver print is copied on an ordinary plate we invariably secure too much contrast unless the original happens to be flat and lacking in contrast. To secure the best results from sepia-toned silver prints a panchromatic plate with a K_3 or similar fully correcting filter should be used. Gum-bichromate, carbon or oil prints and transfers in green, brown, red and similar colors should receive like treatment.

Blue-prints, violet or blue typewriting can be successfully copied by the use of a panchromatic plate together with a deep red filter. In a similar manner stained prints may be copied and the stain removed by the selection of filters appropriate to the color of the stain. This matter has already been touched upon in a former chapter.

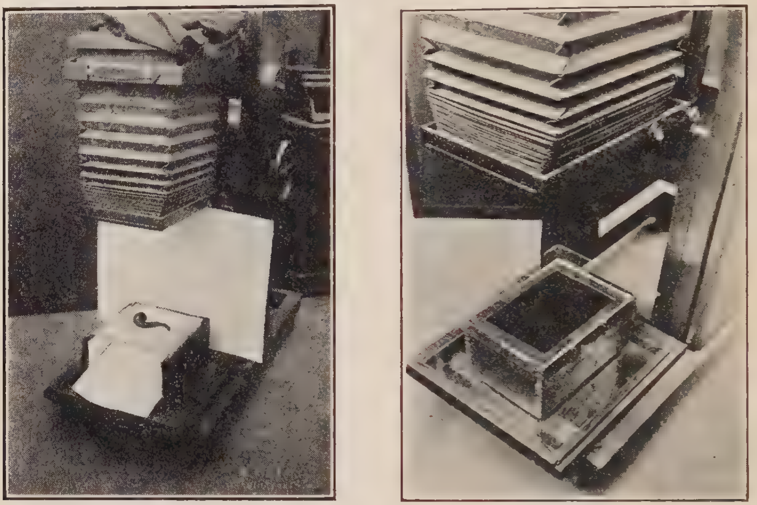
Photography of Small Objects in the Studio.—It is perhaps well that we devote a few lines to this subject as the photography of such articles as knives, watches, small packaged articles, etc., forms a rather large part of the business of a commercial photographer.

In all such work it is a great advantage to be able to use the camera vertically as the articles then remain in whatever position they are placed and it is unnecessary to attach them firmly to a support. Furthermore it is much simpler to make use of the methods to be described for obtaining suitable backgrounds without laborious afterwork such as blocking out with opaque or etching away what is undesirable.

White grounds are easily obtained and all necessity for blocking obviated by the use of a " light box " as shown in Fig. 201. This is simply an ordinary box with the top and front removed, lined inside with a white blotter or coated with aluminum paint and covered with a piece of ground-glass (ground side up) for holding the article to be copied. The reflecting surface may be sloped so as to catch the light to the best advantage or, if the volume of such work justifies it, daylight may be replaced by electric bulbs placed so as to uniformly illuminate the ground-glass above.

Light objects appear to better advantage against a black background. Black velvet is suitable for this purpose but black paper cannot be used as it does not give a pure uniform black owing to its texture. The best results, however, are secured by a " dark box " which is exactly opposite to the " light box " previously described. This is merely a large and deep box painted black on the inside or lined with black paper, the top of which is covered except for an aperture just large enough for the size of background desired. The subject is placed upon a piece of *clear* glass over this black hole and the exposure made.

Sometimes the use of clear glass gives rise to reflections and in such cases it will be necessary to fasten to the under side of the camera a large sheet of black cardboard with a hole cut to accommodate the lens. When this is ineffective we must resort to a hood of tissue paper or tracing cloth to eliminate all direct light. A cone of tissue paper or tracing cloth is made to enclose the space between the lens and the background on which the object is placed so that all direct light is prevented from reaching the glass and reflections removed. The use of this hood of tracing cloth lengthens exposure to a certain extent but reflections which cannot otherwise be removed will yield to this treatment which in such cases is well worth the trouble which it involves.



(*Photos courtesy of D. J. Pratt*)

Fig. 201. Method of Securing White or Black Backgrounds

CHAPTER XXVI

NATURAL COLOR PHOTOGRAPHY

Introduction.—Joseph Nicephore Nièpce writing in May, 1816, to his brother Claude then residing near Kew in England states that one of the problems which he has yet to solve and one which will receive his attention in the future is the *fixation of the colors* by which he probably meant the reproduction of objects in their natural colors. This problem, however, that patient investigator was not destined to solve nor have we who live more than a century later been entirely successful. While the subject has attracted the attention of some of the foremost scientists and much has been accomplished we are still far from a practical process of color photography on paper. We have, nevertheless, made substantial progress and great as the obstacles may now appear there is every reason to believe that the problem will be solved eventually.

It is the purpose of this chapter to record the work which has been done on the subject and to describe the processes now available for photography in natural colors.

Processes of Direct Color Photography.—Seebeck as far back as 1810 found that silver chloride when exposed to the rays of the spectrum partook slightly of the colors themselves and Edmond Becquerel in 1844 reproduced the seven principal colors of the spectrum on a Daguerreotype plate which had been so treated as to form a photo-chloride of silver (Ag : Cl) which has the property of giving a partial reproduction of color which, however, cannot be fixed. Similar processes were described by Robert Hunt, Sir John Herschel, J. W. Draper, Nièpce de St. Victor, G. Wharton Simpson and Poitevin who was able to secure color prints from colored glass transparencies on paper prepared with silver photo-chloride. These prints, however, like all prints involving the use of a photo-chloride of silver could not be fixed while the paper was much too insensitive to allow it to be used in the camera.

Natural color photography along such lines succeeded somewhat better with mixtures of light-sensitive dyes; that is, dyes which fade out to colorless substances. A dye is decomposed only by the light which it absorbs (Grothus-Draper Law) which color is complementary to its own color. Certain aniline dyes bleach comparatively rapidly in light, hence if three such dyes are chosen so as to form the three fundamental colors red, green and blue-violet and these are coated on paper in three separate layers and the whole exposed to a colored object, in red light the green and blue dyes will bleach out, leaving the red; in the same way in blue light, blue will be left as red and green will bleach out and in the case of green, red and blue will bleach out while with colors which are mixtures of these each will be bleached in direct proportion to the amount of the fundamental colors present.

Processes based on this principle were suggested by Cros in 1881, Liesegang in 1889, Ives in 1891, Vallot in 1895, Neuhaus in 1902, Worel in 1902, Szczepanik and Dr. J. H. Smith in 1907, 1908 and 1910.

Despite the apparent simplicity of the process it has never furnished a satisfactory solution to the problem of natural color photography. To secure three dyes having the proper colors and of identical light sensitiveness is not easy and this difficulty together with that of preventing further bleaching of the dyes after exposure and the comparatively low sensitiveness of such mixtures has prevented such methods from progressing beyond the experimental stage.

Direct Color Photography by Processes of Light-Interference.—To understand the ingenious process of color photography worked out by Professor Lippmann of Paris in 1897 it is necessary to review briefly the nature of light and the principle of light-interference. The generally accepted theory of light is that it is a wave motion in an elastic medium known as the ether and is propagated in waves of the transverse type. Suppose two wave motions are made to go in opposite directions by reflection from a highly reflecting surface. Interference will then occur between the incident and reflected waves, resulting in the formation of standing waves. Thus at intervals equal to half the wave-length there will be alternate maxima and minima of light intensity. Now if we place in contact with this highly reflecting surface a "grainless" and transparent emulsion of silver halide, on exposure to light of a definite wave-length the chemical action will be distributed in a number of layers, the maximum action taking place at the crests of the waves and the minimum action at the nodes of the standing waves. On development the layers of exposed silver halide are reduced to the metallic state. Thus there will be formed for each color a set of mirrors the separation of which is exactly equal to one half the wave-length of the light by which they were produced.

When the image is examined perpendicularly by reflected light, the light which is reflected to the eye is the sum of the reflections from these elementary mirrors. The distance between these, however, is one half of the wave-length of the light by which they were produced, therefore when viewed in white light the colors which are not of the proper wave-length are destroyed by interference so that the light reflected from that portion of the image corresponds in color to that which produced the image.

Lippmann's method was to expose a specially prepared fine-grained, transparent emulsion of silver chloride in contact with a bath of mercury which reflected back into the emulsion the waves of light which reached it, thus setting up in the sensitive film the phenomenon of interference described above. While the process is extremely interesting as the verification of certain theories of light and color it is little more than a laboratory experiment. The fine-grained, transparent emulsion employed must be prepared by the worker and special equipment is necessary in order that it may be exposed in contact with a surface of mercury. Furthermore only the pure colors of the spectrum are accurately reproduced; with the ordinary mixed colors of nature the rendering is not so good. Lastly, a lengthy exposure is necessary and the results cannot be duplicated. The process therefore is little more than an interesting laboratory experiment.

Natural Color Photography by Trichromatic Methods.—Promising as such processes of direct color photography may appear theoretically it is with indirect methods involving the separate registration of the three fundamental color-sensations and their subsequent recombination that the greatest progress has been made. All such methods are based upon the discovery by Thomas Young in 1807 of the fact that all color perception is the result of three fundamental color-sensations singly or in various combinations and proportions. That is to say, all of the colors observed in nature are formed by the mixture in various proportions of the three fundamental, or primary, colors, red, green and blue. These three fundamental colors cannot be produced by the admixture of any other colors but from them any color in nature may be matched including white, which is a mixture of all three in equal parts. Hence if on one plate we record the red sensation of the subject by making the exposure through a filter transmitting red only, on another plate the green sensation by the use of a green filter and on a third plate the blue sensation by the use of a blue filter, we have recorded the three fundamental sensations, which singly and in various combinations comprise all the colors of the subject. Recombination of the three-color sensation records may be accomplished in several ways: projection of transparencies in a triple lantern, in various viewing instruments to be described later and by superimposed layers of pigments of the proper colors.

Such, in brief, is the basis of the three-color processes of natural color photography, the principles of which were first clearly realized by Professor James Clerk Maxwell in 1861.

Making the Three Color-Sensation Negatives.—The three negatives may be made with an ordinary camera by making three separate exposures and changing the plate-holders and filters between each exposure. With many subjects, however, there is the liability of movement between exposures while there is always the danger of shifting the camera slightly or upsetting the focus, thus destroying the very necessary correspondence of all three negatives. Much better is the use of a repeating back by means of which it is possible to make all three exposures in fairly quick succession. To avoid trouble from the movement of the subject between exposures, cameras have been devised which make all three negatives at the same time. Owing to the fact that all three negatives must be identical in size and detail it is impossible to use three separate lenses side by side for the difference in the viewpoint of the separated lenses would destroy the exact correspondence of the three negatives. Hence, only one lens may be used (unless we are willing to content ourselves with very distant objects in which case the effect of a small difference in viewpoint is not so noticeable), and the three images formed by means of transparent reflectors or prisms.

It would take us too far afield to consider at any length the various cameras which have been designed for making three-color negatives at a single exposure. There are plenty of them as may be seen by reference to Professor E. J. Wall's *History of Three-Color Photography* which is the most authoritative and complete work on the subject of trichromatic photography.

One of the most successful one-exposure, three-color cameras employing prism separation is that constructed by Sanger Shepherd and Company of London after Ives' British Patent 12,181 of 1900. The two outer sections of the image (Fig. 202) are diverted by the two rhomboidal prisms and form the red and blue negatives while the clear space between the prisms forms a direct image which records the green sensation. The stereo error is very small with this construction and is unimportant for all ordinary subjects.

Cameras using reflectors form the biggest class and while such a construction was first described by Ch. Cros in 1871, to Mr. F. E. Ives belongs the credit for having determined the factors necessary to make it a success. Besides Mr. Ives a large number of other workers have described various forms of one-exposure, three-color cameras using either one or two mirrors references to which may be found in the bibliography or in Professor Wall's *History of Three-Color Photography*. We illustrate in Fig. 203 a camera of this type designed by Mr. E. T. Butler. Part of the light entering the lens on the right is reflected by the first mirror and after passing through the red filter forms the red-sensation negative. The light passing *through* the first reflector strikes the second reflector which reflects a portion of it to

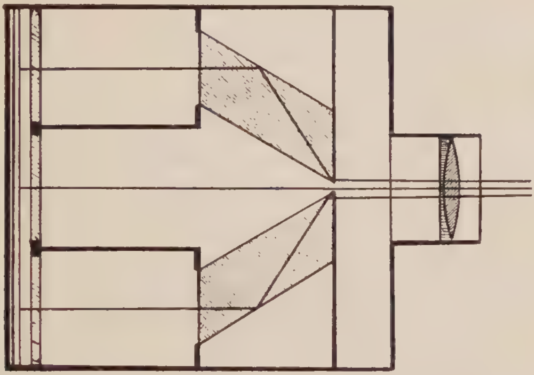


FIG. 202. Sanger Shepherd Three-Color Camera

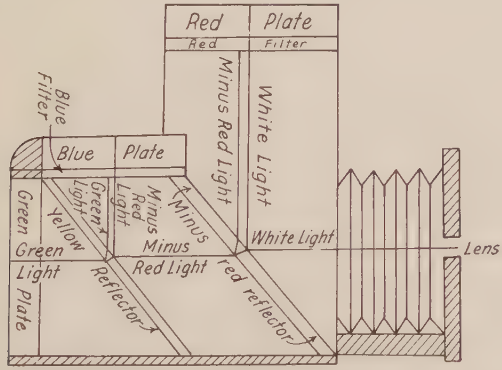

Red
Plate
Red
Filter
Minus Red Light
White Light
Blue Filter
Blue
Plate
Green Light
Yellow
Minus Red Light
Minus
Minus
Red Light
White Light
Lens
Green
Green
Light
Plate
Reflector
red reflector

FIG. 203. Butler's One-Exposure, Three-Color Camera

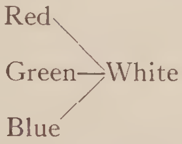
form the blue negative while the light which passes through this reflector forms the green-sensation negative. It is necessary that all three negatives be of the same size and sharpness, hence the distance traversed by the light rays must be the same for all three images. Furthermore it is essential that the reflectors do not produce a double image to overcome which it is necessary to cover the back of the glass with colored gelatine. This color must be the minus color of the taking screen and since the first reflected image forms the red sensation the gelatine coating on the back of this reflector must be minus red or blue-green while that of the second reflector must be minus blue or yellow.

In order to avoid the necessity for a one-exposure, three-color camera, Louis Ducos du Hauron suggested a tri-pack, the three plates or films being bound up together with their respective filters in between. Critical sharpness, however, is impossible with such an arrangement as it is impossible to bring the three emulsions sufficiently close together. This alone might not be a grave objection in certain cases and might be disregarded but for another more serious difficulty. The light which passes through the first plate is diffused by the particles of silver salt making it impossible to secure a halation-free image on the second plate. Halation is of course even more pronounced on the third plate since in this case the light has been scattered by two emulsions. In addition there is the difficulty of adjusting the speeds of the three plates so that each will be properly exposed in the same time. In practice, therefore, attempts to develop such methods have not been very successful.

Additive and Subtractive Three-Color Photography.—The color-sensation negative records by *density* the presence of that particular color in the subject; i.e. the red-sensation negative records the red of the subject in terms of greater or lesser density according to the amount of red present in the various portions of the subject. A positive transparency from this negative will reproduce the red sensation by means of its clearer parts. The parts of the subject containing the purest red will be represented by clear glass, those parts with some red by a medium density while those parts containing no red whatever will be of maximum density. Now if this transparency is viewed in red light it will reproduce the red sensation of the original subject. In like manner the blue and green transparencies will, when viewed in blue and green light, reproduce the respective color sensations of the original subject.

The three records may now be combined and the natural colors of the subject reconstructed by placing each transparency with its proper filter in a viewing instrument constructed like the one-exposure, three-color cameras already considered. This procedure, like most others in three-color photography, was first developed by Louis Ducos du Hauron. It reached its highest development in the hands of Mr. F. E. Ives whose Kromskop has never been surpassed for absolute fidelity in color reproduction.

It is to be noted that in this case colored light is added to colored light. We start with colored light from which we produce white by addition. Hence such processes are termed *additive* processes.



To recombine the three-color sensations on paper or in a single transparency it is necessary to superimpose three separate images of the proper colors. The white paper on which we place our colored images reflects all three primary colors, red, green and blue, which as we know, form white. Now when we print from the red-sensation negative we are printing from the thinner parts, or *those parts which represent the absence of red in the subject.* Hence the red-sensation negative must be printed, not in red, but in a color which completely absorbs all red. But while red is absent either one or both of the two other primary colors may have been present in this portion of the subject. The color of the image, then, must be such that it not only absorbs red but reflects green and blue. It will, therefore, be a minus red or blue-green. The red-sensation negative is thus printed in minus red or blue-green; the green negative in minus green or magenta which absorbs green and reflects blue and red while the blue-sensation negative is printed in minus blue or yellow which reflects red and green but absorbs blue.

Superimposed in full strength these colors absorb all color and the result is either black or gray according to the amount of light reflected. Intermediate colors are produced by the mixture in various proportions of the three fundamental colors while the total absence of color will produce white, since this is the color of the paper base.

It will be observed that in this case we start with white light from which we produce color by subtracting various colors, hence such processes are known as *subtractive* methods.

Red——Minus red or blue-green
White—Green—Minus green or magenta
Blue——Minus blue or yellow

Subtractive Printing Processes.—The principle of the subtractive method has been developed in a wide variety of processes. But few of these, however, are generally employed and these now only in certain quarters, the development of the screen-plate processes having largely killed the interest which was shown in such methods a few years ago. The three-color images for the subtractive processes have been produced by means of trichromatic carbon tissues and lately by three-color carbro; by the production of dye images by mordanting methods, by the transference of dyes or the relief or imbibition process represented by the Pinatype method; by three-color gum-bichromate and by the toning of silver images. While prints by these methods are often quite pleasing from the artistic standpoint there is a tendency, more noticeable in some processes than others, to dull and imperfect colors lacking in brilliancy and transparency owing to the depth of the three superimposed pigment or dye images. This together with the very practical difficulties involved in producing the three images and in properly superimposing them, the complexity of the process and the care and delicacy demanded at every stage, places the process beyond the possibilities of the average worker, hence such methods have failed to make much headway.

Multi-Color Screen Plates.—In just the same way that a painter may secure a certain color by the juxtaposition of dabs of pigment of two colors which when viewed at a distance merge to form a single color, so it is possible to secure on a single plate all three color-sensation records by employing in place of the usual solid color filter a multi-color screen composed of a large number of small color screens evenly distributed and so small as to be practically invisible.

The multi-color screen was the conception of Louis Ducos du Hauron whose patent of 1868 suggested that a sensitive plate be exposed behind a screen composed of fine parallel lines, red, green and blue. The red lines collectively record the red sensation of the subject, while in like manner the green and blue lines collectively record the green and blue sensations respectively, so that all three fundamental color records are secured on a single plate. Consequently when a positive from the original negative is placed in contact with the multi-color screen in the position occupied by the negative, so that the lines in the positive recording the red sensation are behind the red lines of the multi-color screen, the colors of the subject become visible, the same principle being brought into play as in the viewing camera. The multi-color screen plate process of color photography is thus an additive method.

While Louis Ducos du Hauron was the first to develop the idea of a multi-color screen, the practical development of the method is largely due the work of Professor Joly of Dublin and James McDonough of Chicago. The former was granted a patent (B. P. 7743 of 1893, 13,196 of 1894) for a screen plate with parallel red, green and blue lines having a width of about 0.12 mm. (1/200 inch). His patents together with those of an American inventor James McDonough of Chicago, who had devised a similar screen plate but with finer lines, were acquired by a syndicate which placed the process on the market but owing to the difficulties met with in manufacturing the screen plates economically it soon ceased to exist. In succeeding years a large number of patents have been taken out for multi-color screens employing not only ruled lines but various geometrical shapes such as squares, rectangles, circles, etc. As these, with one exception, are no longer on the market we will not linger to consider them but pass directly to the second type of screen plate in which the color screens are distributed at random and do not form a definite geometrical pattern as in the two examples just quoted. The two most conspicuous examples of this type of screen plate are the Lumière Autochrome introduced by A. and L. Lumière of Lyons in 1907 and the Agfa Color Plate.

With a multi-color screen of a definite geometrical pattern the screen may be separate from the sensitive plate; the positive transparency from the negative made behind such a screen being placed in register with another similar screen for viewing purposes. With the second type of multi-color screen, known as the mosaic screen plate, this is impossible and the negative image obtained by development must be chemically reversed. The separate screen-plate method permits of unlimited duplication as one need only make as many positive transparencies as required. With the mosaic screen plate, however, duplicates can only be made by rephotographing the original and at the expense of some loss of brilliancy of coloring. The duplicating method is perhaps the simplest for the beginner in color photography but both processes are well within the possibilities of the amateur who is already conversant with the principles of ordinary photography. As regards the faithfulness of color reproduction there is little difference between the two methods; the colors as reproduced by the mosaic screen plate, however, are supposed to be somewhat softer and with less tendency towards glaring color than the duplicating method. But this difference is so slight as to be of little if any importance.

The Autochrome Plate.—The Autochrome multi-color screen is an example of the mosaic screen and was the first of such to meet with success. The method of preparation is most ingenious. The colored screens are composed of a particular form of starch grains ranging in size from 10/1000 to 15/1000 of a millimeter (.0024 inch). Separate lots of these grains are dyed red, green and blue-violet. These are then mixed in such proportions that the result shows no predominating color and this mixture is spread over the glass plates. The gaps between the grains are filled in by means of extremely fine charcoal dust, after which a layer of waterproof varnish is applied so as to separate the screen from the emulsion which is coated on top of it.

As these starch grains number 6000 to the square millimeter (about 4½ million to the square inch) they are invisible to the eye. When observed with the microscope at a magnification of about 125 times, the appearance of the screen is illustrated in Fig. 204 in which the darker circles represent the blue-colored grains, the half-tone circles the red grains and the lightest circles the green grains. From this it is evident that the grains of any given color are very evenly distributed throughout the screen. This is of course necessary for the opposite state of affairs would result in color patches which would render proper color reproduction impossible.

Over this multi-color screen is coated a thin, highly color-sensitive emulsion. As it is impossible to make this emulsion equally sensitive to all three colors, it is necessary to compensate for this deficiency by means of a filter applied to the lens. As the absorption of light by the multi-color screen is considerable (the Autochrome screen absorbs about 92.5 per cent of the incident light, which amount is still further increased by the compensating filter which must be employed), the working speed of the plate is much less than the ordinary plate or film and is about 4 Watkins or 2.4 H. and D. Very rapid exposures are, therefore, impossible unless the plates are hypersensitized or flashlight is employed. The former operation is not one which should be attempted by the novice.

The Compensating Filter.—The filter supplied by the Lumières is calculated for use with average daylight. As the spectral composition of daylight is never constant, however, and moreover varies greatly in different localities, it is obvious that any single filter is at best a compromise. With the vast majority of subjects, however, and in the temperate zones the filter supplied by the manufacturers is entirely satisfactory but certain subjects which are unusually strong in blue and violet rays require a deeper filter. Thus in early morning or late afternoon when the light is rich in color, subjects including far distances show marked blueness in these portions. Likewise in marine photography or with subjects having wet surfaces, snow scenes, etc., excessive blueness of tone is often observed. Achille Carrara has found that the intense blue of the Italian skies and lakes leads to excessive blueness in the finished result.

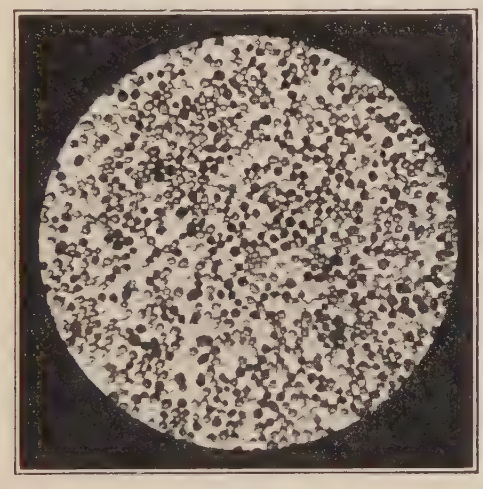


FIG. 204. Autochrome Screen. × 125

In such cases it is necessary to employ a filter absorbing a greater amount of ultra violet than the standard filter. For this purpose an additional screen of æsculine or Filter Yellow K may be employed. Or the usual filter may be supplemented with a Wratten K1 filter for a part of the exposure, or, in extreme cases, for the entire exposure.

The use of filters which absorb too much ultra violet leads to a prevailing yellow tint in the completed transparency.

Special filters are required for artificial light sources. These may be obtained on special order from the manufacturers.

Handling and Exposure of the Autochrome Plate.—The Autochrome emulsion being sensitive to all colors must be handled either in total darkness or by a safelight formed of the Virida papers of the makers. As it is not a difficult matter to load plate-holders in total darkness when one has become familiar with the operation, it is advisable to place the plates into the holders in total darkness. A general greenish tint in the finished positive may often be traced to the use of an unsafe light or to excessive exposure of the plate to the Virida light when loading.

Since the multi-color screen must be in front of the sensitive emulsion during exposure, the glass side of the plate is placed towards the lens. The sensitive film being very delicate it is protected by a piece of cardboard which should not be separated from the plate until the moment of development. Otherwise the delicate film may be damaged and the plate soon develops fog.

Before inserting the slide it is well to brush off any adhering particles of dust or other substances which may be adhering to the glass side of the plate in order that such may not produce a plentiful crop of black spots in the finished result.

As the plate is exposed through the glass a correction is necessary when focusing. If the filter is placed behind the lens this correction is made automatically and this is the proper method to employ with a fixed focus camera or those focusing by scale. If the filter is placed before the lens the ground-glass may be reversed so that the ground side is on the outside. One may move the lens back a distance equal to the thickness of the Autochrome plate (1.8 mm. or 5/64 inch) or employ a Zeiss Ducar filter which automatically compensates for the thickness of the plate and allows the same camera to be used for either ordinary or color work without any inconvenience whatsoever.

Exposure.—As in ordinary photography, and to an even greater degree, success in color photography with screen plates is dependent upon correct exposure. While ordinary plates and films have considerable latitude in exposure, so that one or two times more will still produce a usable negative, the margin of error is very small in color photography, only a few per cent at the most, and correct color rendering cannot be obtained without the proper exposure. Numerous tables have been published for the calculation of exposures for the Autochrome plate but these do little more than indicate the approximate exposure and the factors on which their successful use depends are very difficult to estimate accurately, so the use of tables is not very satisfactory. The only satisfactory method lies in the use of an actinometer such as the Watkins or Wynne to which reference has already been made in a previous chapter. Special color plate meters are supplied by the makers and the use of these is preferable to the regular form because those designed particularly for color work are provided with scales which take into consideration the failure of the reciprocity law which occurs with plates of very low sensitiveness as the Autochrome plate. Owing to the low working speed of the Autochrome plate, the reciprocity law according to which exposure is the product of time and intensity, which are inversely proportional, does not hold. Therefore, in working in feeble light or with a small diaphragm the increase in exposure is *more* than that which would be indicated by the law. According to M. Fauchet, reduction of intensity by one half increases the exposure by about 2.25.

Development.—In 1907 when the Autochrome plate was introduced a pyro-ammonia developer was recommended. This, however, has subsequently been replaced by one of metoquinone and while many of the older workers prefer the former, metoquinone is the best for the novice.

The formula is as follows:

Metoquinone	½ oz.	15 gm.
Sodium sulphite (dry)	3½ oz.	100 gm.
Ammonia 920 (22° Baume)	9 dr.	32 cc.
Potassium bromide	90 gr.	6 gm.
Distilled water to	35 oz.	1000 cc.

For time development dilute one part of the above concentrated stock solution with four parts of water and develop exactly 2½ minutes at 60° F. The Watkins Meter Company supply a special thermometer which shows by the height of the mercury the time for development at any temperature.

Development for a fixed time is suitable only for plates which have been correctly exposed. For all others, preference should be given to a controlled method based upon the time of appearance of the image. To develop by this method one begins development in a diluted developer, taking the time of appearance of the image in this solution. On the appearance of the outlines of the image (the sky being disregarded) the developing solution is strengthened by the addition of a certain amount of concentrated metoquinone developer according to the time required for the first appearance of the image. For a plate up to 4 x 6 inches in size one may begin development in a solution composed as follows:

Water to make	80 cc.	2½ oz.
Concentrated metoquinone developer	5 cc.	85 min.

The following table then shows the amount of concentrated developer to be added upon the appearance of the image and the total duration of development.

Appearance of Outlines of Image (Disregarding Sky) After Immersion.	Quantity of Developer A to Add on Appearance of First Outlines.		Total Duration of Development From Immersion of Plate.	
Seconds			Minutes.	Seconds.
12 to 14	15 c.c.s.	(½ oz.)	1	15
15 to 17	do.	do.	1	45
18 to 21	do.	do.	2	15
22 to 27	do.	do.	3	0
28 to 33	do.	do.	3	30
34 to 39	do.	do.	4	30
Extreme under-exposure 40 to 47	45 c.c.	(1½ ozs.)	3	0
Extreme under-exposure Above 47	45 c.c.	(1½ ozs.)	4	0

(If it is thought desirable for any reason to use a larger volume of developing solution all the quantities given should be increased accordingly.)

M. F. Dillaye recommends that the exact time of appearance be taken by transmitted light and then watching for the moment at which the image, which first appears as a negative, seems completely extinguished, the whole plate presenting the appearance of an even, diffused density. It is at the moment at which this occurs that development should be stopped. If development is continued the image appears as a positive and will be over developed. This method while possibly practical for the advanced worker is not one which the novice should attempt.

One may of course use a desensitizer in which case development may be conducted in a comparatively bright light which makes it easier to determine the appearance of the image. The makers supply in tube form a desensitizer for this purpose, or one may use Aurantia (ammonia salt) at a concentration of 1 part to 1000 of water. Pinakryptol Green may also be employed but some difficulty is experienced at times in removing the stain of phenosafranine from the film so it is better to avoid this agent.

Reversal of the Image.—If we were to fix the image at this stage, we would secure a negative image in complementary colors. The image secured by development represents exactly the reverse of what we require; the silver deposit obstructing the light which should be transmitted while that which should be stopped is being transmitted. It is necessary, therefore, to reverse the image. This involves (1) the removal of the developed silver image and (2) the redevelopment of the remaining silver salt to form the positive image. Accordingly as soon as development is complete the plate is rinsed in a tray of clear, cold water and slipped into the following solution of potassium permanganate which dissolves the silver image:

Potassium permanganate........................	30 gr.	2 gm.
Sulphuric acid 66°..............................	3 dr.	10 cc.
Water to make..................................	35 oz.	1000 cc.

As soon as the plate is covered with this solution the darkroom may be left and all succeeding operations conducted by full daylight, preferably near a brightly illuminated window. In this solution the image rapidly disappears and in 30 or 40 seconds is gone completely. The plate is then taken from the solution and carefully washed for about half a minute in running water and then replaced in the first developer, which should be retained for this purpose. In this the image reappears, this time as a positive, and development is complete within four to five minutes. There is no fear of over development, however, while complete conversion of the silver salt to the metallic state is essential to the brilliancy and the permanency of the image. Care should be taken, therefore, that development is not stopped too soon.

After this second development, the plate is washed for three or four minutes in running water, taking care that the water does not strike the plate with any undue force as the film is very tender at this stage. It is then placed on the drying rack and dried as quickly as possible by means of an electric fan if available. On no account must heat or alcohol be used.

Varnishing.—Although this operation is not absolutely essential it is to be advised since it increases the brilliancy of the colors and serves to protect the image from injury. Varnish for this purpose may be secured from the makers of the plates or prepared according to the following formula:

Crystallizable benzene	100 cc.	5 oz.
Gum dammar	20 cc.	1 oz.

This is flowed over the plate in the usual manner after which the plate is placed on the drying rack in a place away from dust where it must not be disturbed until completely dry. No varnish containing alcohol must be used.

After-Treatment of Autochromes.—If after development the transparency lacks brilliancy and appears dull and brownish a clearing bath may improve matters. For this purpose a 2 per cent solution of sodium bisulphite may be employed.

A general thinness and lack of body in the colors may be due to either over exposure or sometimes, but less often, over development. Intensification will make some improvement. After-treatment of any kind is risky, however, as the film is apt to soften and frill and if carried out directly after development a hardening bath of formaline or alum should be employed. Another point which requires attention when a color plate must be intensified is complete development, otherwise the reduction which takes place in the fixing bath will render the plate useless. Therefore, if intensification appears to be necessary one should make sure that the second development is carried to completion.

For intensification the makers recommend:

A.	Pyrogallic acid	3 gm.	45 gr.
	Citric acid	3 gm.	45 gr.
	Distilled water to	1000 cc.	35 oz.
B.	Silver nitrate	5 gm.	75 gr.
	Distilled water to	1000 cc.	3½ oz.

For use take Solution *A* 10 parts, *B* 1 part. The chromium intensifier may also be used, in fact any method which does not produce a colored deposit.

With the formula given intensification is quite rapid, from 20–30 seconds being sufficient in most cases. The solution slowly turns yellow and becomes turbid and the plate will then be stained unless transferred immediately to a fresh solution. After intensification the plate is cleared by immersion for a few seconds in a 0.001 per cent solution of neutral potassium permanganate, then after a short washing it is placed for two minutes in an acid hypo fixing bath prepared as follows:

Hypo	150 gm.	5¼ oz.
Saturated solution sodium bisulphite	50 cc.	1¾ oz.
Water to make	1000 cc.	35 oz.

(Fixing must not be omitted when the plate has been intensified.)

A final wash of four to five minutes completes the process.

The Agfa Color Plate.—The Agfa color plate, like the Lumière Autochrome, is a mosaic, multi-color, screen plate. The plate itself, as well as the operations of producing color transparencies with it, very closely resembles the Autochrome. The individual color elements are about the same average size as in the Autochrome plate but are more uniform, varying in size from 0.008–0.017 mm. The screen as a whole, however, transmits very nearly twice as much light as the Autochrome; the relative transmissions being 14 per cent for the Agfa plate and 7.5 per cent for the Autochrome. The manipulation of the Agfa color plate differs from that of the Autochrome only in some minor details.

Duplicating Processes of Screen-Plate Color Photography.—Despite the obvious advantages of a duplicating process employing a separate taking screen, such methods have not met with commercial success. One of the earliest of such plates was the Joly-MacDonough, issued about 1892, but discontinued on account of difficulties met with in the production of the taking screen-plate. The Thames plate, introduced several years later, enjoyed a brief spell of popularity and was finally replaced by the Paget Duplicating Process which was essentially an improved Thames plate. This was probably the most successful of the separate screen-plate methods but was discontinued early in 1925. Soon after the disappearance of the Paget method a similar process, but of higher speed, was announced by Chas. Baker of High Holborn, London. This is the only representative of separate-screen methods now on the market.

The Duplex Method.—The exposure is made with the special taking screen in contact with the panchromatic emulsion specially provided for the process. After exposure, the plate is developed in the usual manner, a desensitizer being employed if desired. Intensification or reduction of this negative may be carried out exactly as with other negatives. From this negative any required number of transparencies may be made on black-tone transparency plates and these positives when superimposed in exact register on the viewing screen reproduce the colors of the original subject.

The process thus permits of unlimited duplication without loss of quality since as many transparencies as desired may be made from the original negative by the simple operation of contact printing. Besides this important advantage there is another no less important: i.e. the greater speed of the separate plate method. As shown by Mr. F. E.

Ives the tri-color filters used for making the three color-sensation negatives should divide the spectrum into approximately three equal parts, while the three filters used for viewing purposes should transmit only very narrow bands of the three colors. With the combined plate naturally a compromise must be made for one screen must serve both purposes, but with separate screens the taking screen can be made lighter, thus reducing the exposure required. The Paget process was considerably faster than the Autochrome plate and the new Duplex method is from four to five times as fast as the latter. With a lens having an aperture of *F*/4.5 full exposure in bright light will be secured at about 1/30 of a second, thus permitting hand camera exposures under favorable conditions.

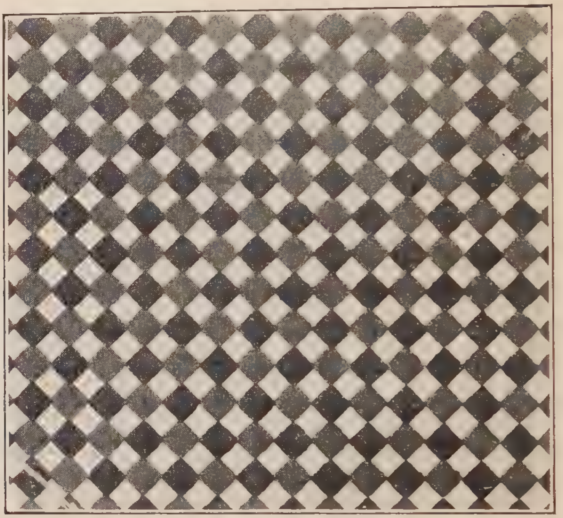


Fig. 205. Duplex Screen

Not all is plain sailing, however, for there are some drawbacks to the separate screen method. The most important is the parallax error arising when the image is not viewed at exactly right angles. When examined from any other than a right angle the patch of silver deposit in the transparency is not in line with its appropriate color screen but the one to the left or right of it. The colors vary, therefore, with the angle from which the image is observed and only by looking at it perpendicularly can the proper colors be seen. This defect of parallax is present to a greater or less degree in all separate plate processes and unfortunately the smaller the color elements the greater is the parallax error.

Other drawbacks are the difficulty of securing perfect contact between the taking screen and the sensitive plate and between the viewing screen and the positive transparency—a condition which becomes increasingly difficult with an increase in the size of the transparency. Registration also presents some difficulties at times but these are but minor matters which do not radically affect the performance of the process.

General Reference Works

Abney—Color Measurement and Mixture.
Bolas, Tallient and Senior—Photography in Colors.
Brown—Color Photography. (Photo-Miniature No. 128.)
Clerc and Camels—La Reproduction Photographique des Couleurs.
Ducos du Hauron—La Triplice Photographique des Couleurs.
Hubl—Three-Color Photography. (English Translation by H. O. Klein.)
Hubl—Die Dreifarbenphotographie.
Johnson—Photography in Colors.
Konig—Natural Color Photography. (English Translation by E. J. Wall.)
Krone—Die Darstellung der naturlichen Farben.
Mees—Color Photography. (Photo-Miniature No. 183.)
Valenta—Die Photographie in naturlichen Farben.
Vidal—Photographie des Colours.
Vidal—Traite pratique de Photochromie.
Wall—Practical Color Photography.
Wall—History of Three-Color Photography.
———Color Photography—Instructions. (Photo-Miniature No. 147.)

APPENDIX

LIST OF THE PRINCIPAL REFERENCE WORKS ON PHOTOGRAPHY IN ENGLISH, FRENCH AND GERMAN

REFERENCES TO TECHNICAL JOURNALS

APPENDIX

A LIST OF MORE IMPORTANT REFERENCE WORKS ON PHOTOGRAPHY

Note.—The following list contains the titles of general reference works only. For works relating to any particular subject see the short bibliographies at the end of each chapter. Works are classified according to the language in which originally printed. Translations are also listed where published in book form. Works which are now out of print have been included where especially valuable. Although these can no longer be obtained from the publishers, they may be located from time to time by the large dealers in second-hand technical works.

Reference Works in English

Abney—Instruction in Photography, 1905.
Abney—Treatise on Photography, 1903.
Abney—Photography with Emulsions, 1896.
Bayley—The Complete Photographer, 1923.
Brothers—A Manual of Photography, 1899.
Derr—Photography for Students of Physics and Chemistry.
Jones—Science and Practice of Photography.
Jones—Photography of Today.
Jones—Cassell's Cyclopedia of Photography, 1912.
Mees and Sheppard—Investigations on the Theory of the Photographic Process, 1907.
Meldola—The Chemistry of Photography.
Mortimer and Wall—The Dictionary of Photography.
Roebuck—The Science and Practice of Photography.
Watkins—Photography—Its Principles and Applications, 1927.
Woodbury—Dictionary of Photography, 1897.
Flint—The Chemistry of Photography, 1918.
The Physical Chemistry of the Photographic Process, 1923.
Photography as a Scientific Implement, 1923.

Reference Works in German

David—Lehrbuch der Photographie.
David—Photographisches Praktikum.
Eder—Ausführliches Handbuch der Photographie, 1920–1930. In four volumes. (The most complete and authoritative work on the subject in existence.)

Eder and Valenta—Beitrage zur Photochemie, 1904.
Goldberg—Der Aufbau der Photographischen Bildes, 1920.
Liesegang—Photographische Physik.
Liesegang—Photographische Chemie.
Luppo-Cramer—Kolloidchemie und Photographie, 1921.
Luther—Die Chemischen Vorgange in der Photographie, 1899.
Lanier—Photochemische Chemie und Photochemie, 1899.
Methie—Lehrbuch der Praktischen Photographie.
Pizzighelli—Handbuch der Photographie.
Plotnikow—Photochemische Versuchstechnik.
Plotnikow—Grundriss der Photochemie, 1923.
Schmidt—Kompendium der Photographie, 1920.
Schmidt—Photographiren.
Schmidt—Vortrage uber Chemie und Chemikalienkunde fur Photographierende.
Stolz—Chemie fur Photographen.
Valenta—Photographische Chemie und Chemikalienkunde, 1920.
Wentzel—Die Photographisch-chemische Industrie, 1926.

Reference Works in French

Belin—Precis de Photographie Generale, 1905.
Braun—Dictionnaire de Chimie Photographique, 1904.
Clerc—La Photographie Practique.
Coustet—Où en est la Photographie.
Davanne—La Photographie, Traite Theoretique et Practique, 1888.
Fabre—Traite Encyclopedique de Photographie, 1889–1906. Eight volumes (The standard reference work in French.)
Henri—Etudes de Photochemie, 1919.
Mathet—Traite Chimie Photographique.
Poulenc—Les Produits Chemiques en Photographie.
Seyewetz—Le Negatif en Photographie.

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Chapter I. The Development of Photography

(For list of general reference works see page 37)

Cromer—Deux Details Historiques. Bull. Soc. franc. Phot., 1923, p. 259.

Cromer—Une Lettre de Nicephore Niepce. Bull. Soc. franc. Phot., 1922, p. 69.

Potonniee—Baynard and The Invention of Photography. Brit. J. Phot., 1914, **61**, 43.

Potonniee—The Cardinal Plate of Niepce. Brit. J. Phot., 1920, **67**, 29.

Potonniee—Date of the Invention of Photography. Bull. Soc. franc. Phot., 1921, p. 312.

Potonniee—The Origin of the Camera Obscura. Bull. Soc. franc. Phot., 1923, p. 52.

Tennant-Woods—Early Daguerreotypers in the United States. Brit. J. Phot., 1920, **67**, 420.

Waterhouse—History of the Camera Obscura. Phot. J., 1900, **40**, 270.

Waterhouse—The Development of Photography with Salts of Silver. Phot. J., 1903, **43**, 159.

Waterhouse—Robert Hooke's Portable Camera Obscura. Phot. J., 1909, **49**, 348.

Waterhouse—Robert Boyle's Portable Camera Obscura. Phot. J., 1909, **49**, 333.

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The Arrangement of the Darkroom

Brown—Fitting up the Darkroom. B. J. Almanac, 1913, p. 523.

Davis—The Arrangement of a Darkroom. Amer. Phot., 1913, **7**, 198.

Gear—Fitting up the Darkroom. Phot. J., 1911, **51**, 338.

King—That Model Darkroom. Amer. Phot., 1920, **14**, 67.

Kraft—Shutter for Darkroom Window. Amer. Phot., 1915, **9**, 664.

Lafer—My Darkroom. Amer. Phot., 1913, **7**, 579.

Roberts—The Evolution of a Darkroom. Amer. Phot., 1916, **10**, 16, 238.

Weston—Darkroom Fittings. Phot. J., 1921, **61**, 25.

On Darkroom Safelights

Hartridge—Darkroom Safelights. Brit. J. Phot., 1915, **63**, 593.

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Mees—Darkroom Illumination by Reflected Light. Brit. J. Phot., 1915, **62**, 693.

Mees and Baker—Measurement of the Efficiency of Darkroom Light Filters. Phot. J., 1907, **47**, 276.

Neugebauer—Preparation of Darkroom Safelights. Brit. J. Phot., 1923, **70**, 397.

Pledge—Darkroom Illumination. Brit. J. Phot., 1921, 68, 249.

Stenger—Liquid Darkroom Safelights. Brit. J. Phot., 1905, 52, 732; Zeit. wiss. P., 1905, 2, 233.

Trivelli—Lights for the Darkroom. Brit. J. Phot., 1911, 58, 474, 494, 533, 628, 777, 872, 957; 1912, 59, 22.

Chapter III. Photographic Optics

(For list of general reference works see page 87)

Focal Length and Its Determination

Jobling and Salt—Measurement of Focal Length by Clay's Method. Brit. J. Phot., 1922, 69, 137.

Johnson—Focal Length of a Lens or Lens Combination. Phot. J., 1906, 46, 300.

Johnson and Gleichen—Summary of Laws Relating to Focal Length. Phot. J., 1913, 53, 183.

Lambert—Measuring the Focal Length of a Lens. Phot. Journal of America, 1923, 60, 87.

Lockett—A New Method for Finding the Focal Length of Lenses. Brit. J. Phot., 1915, 62, 411; Brit. J. Phot., 1922, 69, 434.

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Brown—Theory and Practice of Depth of Focus. Brit. J. Phot., 1922, 69, 492, 507, 521, 534.

Browne—A Simple Depth Chart. Brit. J. Phot., 1923, 70, 775.

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Fraprie—Table of Hyperfocal Distances. Brit. J. Phot., 1915, 62, 795.

Johnson—Calculating the Distance Beyond Which Everything is in Focus. Phot. J., 1906, 46, 329.

Lee—Chart for Finding the Depth of Focus. Phot. J., 1922, 62, 229; Brit. J. Phot., 1922, 69, 135.

Piper—Depth Simplified. Brit. J. Phot., 1905, 52, 1004.

Piper—Depth and the Sine Condition. Brit. J. Phot., 1906, 53, 125.

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Rudolph—A New Depth Test Object. Phot. Rund., 1921, p. 266.

Scale of Optical Reproduction

Brown—Scale of Optical Reproduction. Brit. J. Phot., 1921, 68, 667, 685, 702.

Loss of Light in Lens Systems by Absorption and Reflection

Cheshire—The Loss of Light in Lenses. Brit. J. Phot., 1912, 59, 597, 645.

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Nutting—The Brightness of Optical Images. Phot. J., 1914, 54, 187.

Odencrants—The Experimental Determination of the Luminosity of Photographic Objectives. Nord. Tids. Fot., 1925, 9, 21; S. I. P., 1925, 5, 87.

Zschokke—Factors Other than Aperture in the Rapidity of a Lens. Brit. J. Phot., 1912, 59, 823.

Chapter IV. The Aberrations of the Photographic Objective

(*For list of general reference works see page 104*)

On the Aberrations of Photographic Objectives and the Testing of Objectives

Bennett—Aberrations of Long Focus Anastigmatic Objectives. Bur. Standards Paper, No. 494.

Bow—On Photographic Distortion. Brit. J. Phot., 1861, 8, 417.

Bow—On the Curvature of the Image. Brit. J. Phot., 1863, 10, 228.

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Carson—The Correction of the Aberrations of a Photographic Objective. Phot. J., 1903, 43, 188, 278.

Chalmers—The Aberrations of Photographic Objectives. Phot J., 1907, 47, 374.

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Grubb—On the Equalization of the Photographic Image in Fields of Large Angle Projected upon a Flat Surface. Brit. J. Phot., 1863, 10, 401.

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"Rhomb"—Achromatism. Phot. J., 1908, 48: Part I, p. 320; Part II, p. 333; Part III, p. 343; Part IV, p. 375. Phot. J., 1909, 49: Part V, p. 54; Part VI, p. 126.

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Steinheil—Das Prufen und Wahlen der Photographen-Objectiv. Phot. Korr., 1869, 6, 49.

Taylor—Axial Aberrations of Lenses. Brit. J. Phot., 1918, 65, 101, 113, 124.

Taylor—Lens Testing Instruments. Phot. J., 1902, 42, 40.

TILLYER AND KERR—Lens Testing Instrument. U. S. P., 1, 383, 578.

TWYMAN—On the Use of the Interferometer for Testing Photographic Objectives. Phot. J., 1919, 59, 239.

THOMPSON—Zonal Aberration and its Consequences. Phot. J., 1900–01, 40, 383. British Journal Almanac, 1902.

Chapter V. The Photographic Objective

(For list of general reference works see page 148)

PAPERS ON THE DEVELOPMENT OF THE OBJECTIVE

BUNGER—Genesis of Modern Lenses. Brit. J. Phot., 1907, 54, 638, 660, 736.

CLAY—The Photographic Lens from a Historical Point of View. Phot. J., 1922, 62, 459.

DALLMEYER—The Evolution of Modern Lenses. Phot. J., 1900–01, 40, 64.

LUMMER—Beitrage zur photographischen Optik. Zeitsch. Instrument, 17, 208, 225, 264.

VON ROHR—Uber die Bedingungen fur die Verzeichnungsfreiheit optischer Systeme mit besonderer Bezungnahme auf die bestehenden typen Photographischer. Zeitsch. Instrument, 1898, 17, 271.

VON ROHR—Beitrage zur Kenntniss der geschichten Entwicklung der Ansichten uber die Verzeichnungsfreiheit photographischer Objectiv. Zeitsch. Instrument, 1898, 18, 4.

VON ROHR—Uber die Lichtvertheilung in der Brennebene photographischer Objectiv mit besonderer Berucksichtigung der bei einfachen Landschaftslinsen und symmetrischen Konstruction auftrenden Unterschiede. Zeitsch. Instrument, 1898, 18, 171, 197.

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HARTING—Recently Discovered Objectives of Petzval and Zinc-Sommer. Phot. Ind., 1924, p. 1030.

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MERTE—The Tele-tessar. Cent. Zeit. Mech. Opt., 1921, p. 245.

MIETHE—Symmetrisches Objectiv ohne Astigmasie. Phot. Mitt., 1888, 25, 123.

PUYO AND PULLIGNY—The Anachromats. Brit. J. Phot., 1906, **53**, 184.
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VON ROHR—Uber das Planar. Eder's Jahrbuch, 1898, **12**, 70.
VON ROHR—Uber altere Portratobjektive. Zeitsch. Instrument, 1901, **21**, 40.
WENHAM—Achromatic Periscope. Brit. J. Phot., 1874, **21**, 597, 621; Brit. J. Phot., 1875, **22**, 22.

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ALDIS—The Stigmatic. B. P. 16,640/95, D. R. P. 92,582/95.
ALDIS—The Aldis Triplet. B. P. 5170/02.
ARBEIT—Symmetrical Anastigmatic Objective. D. R. P. 135,742/01, D. R. P. 250,781/11, B. P. 16,331/11.
BECK—Isostigmar. B. P. 27,180/1906, B. P. 14,673/1908, D. R. P. 194,267.
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BOOTH—Pentac. B. P. 151,506/20.
CLARK—Objective. U. S. P. 399,499/1889.
DALLMEYER—Rapid Rectilinear and Modified Petzval Lens. B. P. 2502/1866.
DALLMEYER—Rectilinear Landscape Lens. B. P. 1853/1888.
DALLMEYER—Single Landscape Lens. B. P. 2539/1864.
DALLMEYER—The Achromatic Triplet. B. P. 396/1866.
GOERZ—*Cf.* Von Hoegh and Zschokke.
GRAF—Graf Anastigmat. U. S. P. 1,463,132/1923, B. P. 22,400/1910, U. S. P 981,412/11.
GRUBB—Grubb's Lens. B. P. 1968/1871.
GUNDLACH—Turner-Reich Anastigmat.
HARRISON—The Globe Lens. B. P. 2496/1860.
KAEMPFER—Kollinear. D. R. P. 90,482/1895, D. R. P. 91,883/1895.
KOLLMORGEN—Aristostigmat. D. R. P. 125,560.
LAN—Davis-Serrac. B. P. 27,518.
LACOUR BERTHIOT—Anastigmat. B. F. 374,045/1907.
LACOUR BERTHIOT—Stellor. B. F. 456,484/1913.
LEE—Unsymmetrical Anastigmatic Objective. B. P. 209,371.
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MARTIN—Omnar. O. P. 8364/1901.
MORRISON—Wide Angle Lens. U. S. P. 126,979.
POLAK—Hyperchromatic Objectif. B. P. 201,920.
RUDOLPH—Doppel-Anastigmat. B. P. 4692/1893, B. P. 19,509/1894.
RUDOLPH—The Planar. D. R. P. 92,313, B. P. 27,635/1896.
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RUDOLPH—Plasmat. B, P. 161,091/1920.

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Rodenstock—Imagonal. D. R. P. 177,266.
Schroeder—Concentric Lens. B. P. 5194/88.
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Steinheil—Orthostigmat. D. R. P. 76,662/93. Orthostigmat Type II. D. R. P. 88,505/93.
Steinheil—Antiplanet. D. R. P. 16,354/81, B. P. 1602/81.
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Steinheil—Portrait Aplanat. B. P. 1124/74.
Steinheil—Group Aplanat. D. R. P. 6189/79.
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Taylor, H. D.—Cooke Triplet. B. P. 22,607/93, D. R. P. 81,825/94, B. P. 15,107/95, D. R. P. 86,757/95, B. P. 24,391/1905, B. P. 3398/1905, B. P. 7661/1906, B. P. 3799/1912.
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Von Hoegh—The Celor and Syntor. D. R. P. 109,283/98, B. F. 278,768/98, B. F. 329,394/03, D. R. P. 202,083/07.
Voigtlander—Modification of the Petzval Objective. D. R. P. 5761/78, B. P. 4756/78.
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Zeiss—Triplet Anastigmat. D. R. P. 86,757/95, B. P. 6328/13, B. F. 455,546/13.
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Zschokke—Dogmar. D. R. P. 258,495/12, B. P. 833/13, B. F. 453,230/13.

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Lan Davis—The Large Adon. B. P. 1185/14.
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Martin—The Busch Bis-Telar. B. P. 15,732.
Merte—The Tele-tessar. B. P. 145,548/19, B. P. 179,529/21, U. S. P. 1,467,804/23.
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(*For list of general reference works see page 167*)

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Chapter XIII. The Technique of Development

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Chapter XVII. Printing Processes with Silver Salts

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SUBJECT INDEX

Aberration, chromatic, 89
  comatic, 94
  spherical, 92
Absorption, loss of light in lenses by, 84
Achromatic, 90
  lenses, single, 106, 107
Acid fixing baths, 323, 324
  extra hardening baths, 325
  troubles with, 325
Actinometers, 248
  correction for special subjects when using, 250
  for carbon printing, 468
Additive methods of color photography, 542
Adon lens, 147
Adurol, 278
  formula for use of, 287
Agfa color plate, 553
Aldis lenses, 136
Alkali, acetone as a substitute for, 297
  carbonates in development, 295
  caustic, 297
  function of in development, 258
  proportion of to developing agent, 296
Amidol, 280
  for bromide paper, 274
  formula for use of, 287
  preservatives of, 281
Ammonia, ripening of emulsions with, 158
  influence in fixation, 319
  in development, 295
Ammonium chloride, influence on rapidity of fixing, 317
Anachromatic lenses, 107
Angle of view, 74
Aperture, effective, 83
  inconstancy of, 83
  relative variation with subject, 85
Aplanat, 109
  types of, 110
Apochromatic, 92
Aristostigmat lens, 121
Artificial latent images, 195
  with hydrogen peroxide, 196
  with sodium arsenite, 197
Artificial light, for copying, 522
  for projection printing, 393
  filter factors with, 186
Astigmatism, 98
Autochrome plate, 546
  after treatment of, 552
  development of, 549
  exposure of, 548
  filters for, 547
  reversal of, 551
Aviar lens, 136

Back, reversible, 48
  swing, 46
Baynard's work in photography, 18
Bichromated colloid printing processes, chemistry of, 462
  history of, 33
Bis-telar lens, 144
Bitumen of Judea, Niepce's process with, 11
Bleaching of bromide prints in bromoil process, 505
  in sulphide toning, 440
Bromide, advantage of excess of in emulsions, 156
  density depression with, 273
  effect of on characteristic curve, 272
  effect on development of fog, 274
  effect on velocity constant and gamma infinity, 274
Bromide papers, history of, 32
  developers for, 372
Bromoil process, 35, 462

    bleaching the print, 505
    bromide papers for, 503
    pigmenting, 508, 511
    producing relief in, 508
    theory of, 462
    type of print for, 504
Bromoil transfer, 512
    bromide print for, 512
    bromoil for, preparation of, 513
    chemical transfer, 517
    multiple transfer, 518
    papers for, 514
    presses for, 515
    processes in, 516

Cabinets, drying, 63
Calotype process, 20
Camera, adjustments of, 45
  box, 38
  copying, 523
  enlarging, 390
  hand, 40
  miniature, 38
  professional view, 42
  reflex, 43
  trichromatic, 540
Camera obscura, history of, 1
  with lens, 4
  use of by Niepce, 11
Carbon printing, 33, 463
    actinometers for, 468
    chemistry of, 462
    continuing action of light in, 469
    development of prints, 469
    exposure in, 467
    sensitizing tissues, 465
    tissues for, 464
    transfer, single and double, 465, 471
    transfer to rough paper, 472
Carbro printing, 462, 473
    bromide print for, 474
    development in, 478
    multiple printing, 479
    on bromide print, 479
    sensitizing formulas, 475
    sensitizing tissues for, 476
    transfer, 477
Catalytic theory of persulphate reduction, 350
Celor lens, 119
Characteristic curve, method of obtaining, 222
    significance of, 223
    effect of development on, 235
    effect of soluble bromide on, 272
Chromatic aberration, 89
Chromium intensifier, 357
Circle of confusion, 78
Clouds, introducing in projection printing, 414
Collinear lens, 116
Collodion process, Archer's, 23
    inconveniences of, 23
    modifications of, 25
Collodion emulsion, 26
Color contrasts, photographing, 189
Color photography, 537
    direct, by bleaching of dyes, 537
    direct, by light interference, 538
    by trichromatic methods, 539
    by multi-color screen plates, 544
Color Sensitizing, by bathing, 180
    dyes for, chemical constitution of, 170
    dyes for, sensitizing properties, 177
    theories of, 175
Color-Sensitive plates with incorporated filters, 184
Condensing lenses, 399
    with diffusing media, 401
Conjugate focal distances, 74
      in projection printing, 409
Constant density ratios, 232
Cooke lens, 134, 135
Copper intensification, 359
Copying, artificial light for, 522
  black and white objects, 530
  cameras for, 523

  colored objects, 533
  exposure in, 527
  focussing in, 524
  illumination in, 521
  objectives for, 523
  photographs, 532
  to scale, 525
Curvature of field, 95

Dagor lens, 115
Daguerreotype process, 15
    later history of, 17
Dalmac lens, 133
Dallon lens, 144
Darkroom, arrangement of, 54
  illumination of, 56
  sinks, 55
  size of, 52
  ventilation of, 53
  water supply in, 55
Density, Beer's law, 217
  constant ratios, 232
  definition of, 217
  dependance upon method of measurement, 216
  growth with exposure, 235
  growth with time of development, 260
  ratios and opacity ratios, the difference, 233
  soluble bromide, action on, 273
Densitometers, absorption, 215
  polarisation, 214
  photo-electric, 216
Depth of Focus, factors controlling, 79
    theory of, 77
Desensitizing, agents, 298
  of autochromes, practice of, 299
  Watkins factor, effect on, 300
  value of, 298
Developing Agents, classification of, 276
    developing characteristics of, 286
    formulae for, 287
    group relations in, 284
    phenolate compounds as, 289
    reduction potential of, 275
    relative reducing energy, 274
    source and derivation, 277
Development, function of alkali in, 258
  factorial, 259, 302
  high temperature, 312
  induction period of, 259
  invasion phase of, 253
  of enlarged negatives, 417
  of lantern plates, 424
  of papers, 374, 375
  of process plates, 531
  perfect negative and, 234
  precipitation phase of, 256
  reduction phase of, 255
  reproduction of contrast in, 232
  soluble bromides in, 257
  sulphites in, 257, 293
  structure of gelatine and, 253
  temperature, effect on, 265
  thermo, 305
  time of, for given gamma, 262
  time of, for various temperatures, 271
  velocity of, 259, 261
Development Papers, 368
    alteration of contrast, 381
    amidol developer for, 374
    development of, 374, 375
    fixing of, 321, 378
    glazing of, 383
    washing of, 379
Diaphragm, Le Clerc, 525
  systems of notation, 81
  variation in value of with distance of subject, 85
Digestion of emulsions, 158
    theory of, 160
Dispersion of light, 67
Dispersoid theory of persulphate reduction, 351
Distances, conjugate focal, 74
Distortion, 97
Dogmar lens, 120
Drying, cabinet for, 63
  d-o-p prints, 405
  gum-bichromate prints, 485
  lantern slides, 425
  carbon tissues, 466

Duplicating processes of screen-plate photography, 553
Dyes, local intensification with, 363
  color sensitizing, 170, 177

Edinol, 281
  formula for, 287
Eikonigen, 284
  formula for, 287
Emulsion, 26
  appearance under microscope, 162
  advantage of excess halide in, 156
  classes of, 153
  collodion, history of, 26
  digestion of, 158, 160
  emulsification, 156
  fog in, 159
  gelatine, history of, 27
  gelatine in, 150
  iodides in, 157
  preparation of, 153, 155
  washing of, 160
Ernostar lens, 139
Exposure in negative making, 240
  actinometers, use of in calculating, 248
  atmosphere, influence of, 240
  latitude in, 230
  speed of plate, effect of variations in, 246
  subject, influence of, 242
  variation of light intensity, influence of, 240
  visual exposure meters for calculation of, 250

F system, 82
Factorial development, 302
    accuracy of, 303
    factors for, 303
    of developing papers, 375
    of lantern slides, 424
Film, introduction of, 30
Filters, 183
  autochrome, 547
  contrast, 183
  lens definition, effect on, 533
  orthochromatic, 184
Finders, 51
Fixing, 314
  ammonium chloride, effect on, 317
  concentration, effect on, 316
  mechanism of, 315
  necessity for complete in sulphur toning, 433
  of developing papers, 321, 378
  of p-o-p papers, 388
  of lantern slides, 452
  velocity constant of, 315
  when complete, 319
Fixing Bath, acid, 323
    hardening, 324
    troubles with, 325
    exhaustion of, 320
    extra hardening, 325
    plain, 322
Flare, 100
Focal length, 71
    and size of image, 72
    and perspective, 72
    choice of, 73
Focal distances, conjugate, 74
Focus, principal, 71
  depth of, 77
Focussing, parallax method, of, 524
Fog, 334
  chemical, 336
  dichroic, 338
  emulsion, 336
  light, 335
  sulphite, 337

Gamma, 234
  calculation of, 237
  characteristic curve and, 235
  time of development for given, calculating, 262
Gamma infinity, 238
  bromide, effect of soluble on, 274
  calculation of, 239
Gauss theory of image formation, 69
Gaussian objectives, 120
Gelatine, 150
  sensitizers, 151
Gelatino-citro-chloride paper, 31

Glass, introduction of as negative base, 21
Globe lens, 109
Glycin, 282
  formula for, 287
Graduates, 61
Graf anastigmat, 126
Gum bichromate process, 481
  coating papers, 484
  development in, 486
  drying papers, 485
  effect of variations in coating mixtures, 484
  exposure, 486
  formulas for coating, 482
  materials for, 482
  registration in, 487
  the negative for, 482
Gum bromide process, 489

Heliar lens, 137
Holostigmat lens, 116
Hoods, lens, 51
Hydroquinone, 278
  formulas for, 287
  reactions in development, 256
Hypersensitizing, 181
Hypo, action on silver halides, 314
  eliminators of, 331
  tests for, 330
  toning with acid, 437
  toning with alum and, 434

Illuminants for projection printing, 394
  arc, 395
  incandescent, 396
  mercury vapor, 395
Image, intensity of optical, 80
  formation by lenses, 68
  Gauss theory of, 69
Inertia, as a measure of speed, 224
  variation of, 224
Intensification, how secured, 353
  local with dyes, 363
  of lantern slides, 430
  of prints, 382
  sensitometry of, 360
Intensifying processes, classification of, 361
  chromium, 357
  copper, 359
  lead, 359
  mercuric-iodide, 355
  mercury, 353
  Monckhoven's method, 355
  silver, 356
  sulphide, 360
  uranium, 358
Iron printing processes, 460
Iron toning processes, 448
Isostigmar lens, 127

Kallitype process, 459

Lantern slides, 419
  binding, 426
  by projection, 421
  developers for, 423
  development of, 424
  exposing, 421
  fixing, washing, and drying, 425
  intensification of, 430
  masking, 425
  negative for, 419
  physical development of, 428
  plates for, 419
  printing frame for, 420
  reduction of, 429
  spotting, 426
  thiocarbamide, warm tones with, 429
  toning of, 429
  warm tones by development, 427
Latent Image, 195
  artificial, 195
  formation at low temperatures, 205
  intensification of with hydrogen peroxide, 196
  oxidizing agents, action on, 200
  photo-regression, 199
  photosalts, 202

physical development of, 201
reversal of, 198
theories of, 204, 205
Lenses, achromatic, 105
anastigmatic, 114
aplanatic, 108
apochromatic, 92
image formation with, 68
loss of light in, 84
nodes of, 70
speed of, 81

Magnar, lens, 143
Meniscus, objective, Wollaston's, 105
Mercuric cyanide as a desensitizer, 299
Metol, 282
formula for, 287
and adurol, 288
and glycin, 288
and hydrochinon, 288, 309

Negative, perfect, H. & D. definition of, 228
enlarged, making, 415
faults in, 333
for gum bichromate, 482
for lantern slides, 419
for projection printing, 407
scatter of light in, 408
Niepce, his work, 8
Neostigmar lens, 127
Nodes of lenses, 70
positions of, 71

Objective, achromatic, 106
aplanat, 108
Gaussian anastigmatic, 120
meniscus, 105
portrait, 110
semi-achromatic, 107
symmetrical anastigmatic, 115
symmetrical air-space anastigmatic, 118
telephoto, 140
triple, anastigmatic, 133
unsymmetrical anastigmatic, 128
Oil process, 35
brushes for, 495
Duvivier's process, 502
exposing, 498, 501
papers for, 495
pigmenting, 499
pigments for, 496
sensitizing, 497
Orthochromatic filters, 184
in landscape photography, 186
in portraiture, 187
multiplying factors of, 185
Orthostigmat lens, 116
Ortol, 283
formula for, 287

Papers, early negative processes, 20
Papers, printing, adapting to negative, 366
characteristics of, 364
correct rendering, limits of, 365
exposure scale of, 365
total scale of, 365
Paraminophenol, 280
formula for, 287
Pentac lens, 138
Permanganate, reduction with, 348
Persulphate, reduction with, 351
theories of, 349
Peroxide, artificial latent image with, 196
intensifying action on latent image, 196
Perspective, 72
Petzval portrait lens, 110
Phenolate compounds as developers, 289
Phenosafranine, desensitizing with, 298
Photochemical action, early records of, 5
Photochemical and photophysical change, 194
Photography, definition of, 1
Photoregression, of latent image, 199
Physical development, after fixation, 201
of lantern slides, 428
Pinakryptol as a desensitizer, 298

  green, 298
  yellow, 299
Plasmat lens, 123
Plates, Agfa for color photography, 553
  autochrome, 546
  lantern, 419
  orthochromatic, 171, 177
  panchromatic, 177
  process, 530
  wet, 23, 25
Plate Speeds, actual and H. & D. speeds, variation, of, 225
    effect of soluble bromide on, 272
    inertia as a measure of, 224
    table of different systems of expressing, 246
Platinotype process, 32
    commercial papers for, 453
    exposure and development, 454
    theory of process, 452
    variation of color in, 456
    variation of contrast in, 455
Portrait, first by photography, 17
Powder printing processes, 490
Printing-out-papers, 31
  exposing, 385
  fixing of, 388
  toning, 386
Printing Processes, bromide, 32, 370
    bromoil, 35, 462, 503
    carbon, 33, 462, 464
    carbro, 33, 462, 473
    gum-bichromate, 33, 462, 481
    iron, 460
    oil, 35, 462, 495
    platinum, 32, 452
    P-O-P, 31, 385
Projection printing, 390
    artificial light for, 393
    condensers in, 399
    diffusing media in, 401
    daylight for, 392
    easel for, 412
    introducing clouds in, 414
    negative for, 407
    objective for, 403
    self-focussing apparatus for, 394
Protar lens, early unsymmetrical, 128
    series VIIa, 117
Pyrocatechin, 278
  formula for, 287
Pyrogallol, 279
  formula for, 287
  with glycin, 288
  with metol, 288
  time development with, 308

Radiar lens, 145
Rapid rectlinear lens, 109
Reciprocity law, failure of, 213
Reducers, 345
  Belitzski's, 347
  Farmer's, 346
  iodine-cyanide, 348
  mercury cyanide, 347
  permanganate, 348
  persulphate, 351
  proportional, 349
  super-proportional, 350
Reduction, chemical in development, 256
  local, 362
  of prints, 382
  of lantern slides, 429
  proportional, 349
  subtractive, 345
  super-proportional, 350
Refraction, of light, 65
  index of, 66
Reflection, loss of light in lenses from, 84
Reversal, of autochroms, 551
  of latent image by chemical reagents, 198
  of latent image by exposure, 198

Safelight, 59
  efficiency of, 60
  for developing papers, 374
Satista paper, 457
Schwellenwert method of speed determination, 209
Schwarzschild constant, 213

Screen plates, 544
Sensitivity centers, 164
        action of oxidizing agents on, 200
        role in exposure, 207
Sensitizing, color, by bathing, 180
    blue print paper, 460
    carbon tissue, 465
    carbro tissue, 476
    oil papers, 497
    substances in gelatine, 151
Sensitometry, 209
    characteristic curve, 222
    constant density ratios, 232
    densitometers for, 214
    density-exposure relation in, 221
    developers and development in, 220
    development and contrast, 232
    exposure in, 219
    gamma, 234
    H. & D. speeds and actual speeds, 225
    inertia, 224
    latitude in, 230
    perfect negative, definition of in, 228
    reciprocity law, failure of, 213
    sensitometers for, 211
    standard light sources, 210
    threshold method of, 209
    wedge methods of, 227
Shutters, 49
Serrac lens, 132
Silver halide, action of hypo on, 314
        photoelectric properties of, 206
        sensitivity of various, 154
        sub-halides, 203
        visible darkening of, 203
Sinks, 55
Spectrum, 168
    photochemical action of on the silver halides, 169
Spherical aberration, 92
        and depth of focus, 79
Spots on negatives, 342
Stains on negatives, 339
Stigmatic lens, 128
Sulphites, action in developers, 257
    control of developer stain with, 295
    forms of, 293
    stock solutions of, 294
Sulphur toning, 431
        alum and hypo, 434
        indirect, 440
        mercury-sulphide, 444
        necessity for complete fixing, 433
        prints for, 431
        rebleaching of toned prints, 443
Superproportional reducers, theory of, 350
Swing back, 46
Swing front, 47

Talbot, life and work, 18
Tanks, 61
    commercial, 62
Telecentric lens, 144
Teledynar lens, 147
Telekinic lens, 145
Teleobjective, 140
    anastigmatic, 143
    compound, 140
    early fixed magnification, 142
Temperature, calculation of time of development at given, 271
    development at high, 312
    sensitiveness of plate at low, 205
Temperature coefficient of development, 267
            calculation of, 268
            of various developing agents, 267, 269
Tessar lens, 130
        constructions based on, 131, 132
Thermo development, 305
        efficiency of, 311
        developers and tables for, 306
        with glycin, 310
Toning, of developing papers, 431
    of lantern slides, 429

of p-o-p, 386
Toning processes, alum-hypo, 434
    copper, 445
    indirect sulphide, 443
    iron, 448
    mercury-sulphide, 444
    miscellaneous processes, 451
    nitro-sulphide, 439
    polysulphide, 437
    uranium, 446
    vanadium, 449
Transparency, sensitometric definition of, 217
Trays, 61
Trichromatic photography, 539
Triplet objectives, anastigmatic, 133
  early, 108
Tripods, 50

Unar lens, 129
Unofocal lens, 125
Uranium, intensification with, 358
  toning with, 446

Vanadium, toning with, 449
Velocity constant, of development, 261
    of fixation, 315
View, angle of, 74

Washers, efficiency of, 327
  for negatives, 328
  for prints, 379
Washing, mechanism, of, 326, 330
Watkins factor, 259, 302
    for various developers, 303
    variation with desensitizers, 300
Wedgewood, his work, 8
Wedges, optical, desensitometers using, 215
  in sensitometry, 227

INDEX OF AUTHORS

Abegg, 164, 205
Abney, 30, 156, 157, 169, 204, 213, 215, 278, 469
Adams, 174
Adamson, 241
Aldis, 136
Allen, 206
Amor, 332
Anderson, 479
Andreson, 284
Arago, 3, 15
Aristotle, 1, 5

Bacon, 2
Baines, 315
Baekeland, 32, 200
Barbaro, 4
Bayard, 18
Beck, 127
Beechey, 26
Belitski, 347
Bennett, 29, 156, 360, 444
Blake-Smith, 466
Bolton, 29
Bolton & Sayce, 26
Booth, 138, 144
Bow, 103
Burgess, 28
Bullock, 438, 441
Butler, 541

Callier, 217, 407
Charles, 525, 528
Clark, 201, 220, 331
Clarke, 175
Collins, 413
Crabtree, 325, 341
Cros, 538
Crowther, 281, 506

Daguerre, 9, 12
Dallmeyer, 106, 107, 109, 113, 128, 132, 133, 138, 141, 144, 147
Da Vinci, 2
Davis, 211
Davy, 8
Debenham, 86
Dillaye, 550
Draper, 17, 169, 194
Drinkwater, 435
Dundon, 181
Du Hauron, 542, 543, 544
Duvivier, 502

Eastman, 30
Eder, 30, 31, 32, 156, 157, 158, 164, 175, 176, 194, 204, 276, 347, 462
Eder & Toth, 445
Ermen, 296

Farmer, 35, 36, 346, 362
Ferguson, 267, 445
Forch, 85
Fox-Talbot, 18, 19, 31, 33

Gard, 397
Gauss, 69, 120
Glover, 505
Goddard, 17, 107
Goerz, 115, 118, 119, 120
Goldberg, 227
Graf, 126
Gross, 203

H. & D., 210, 212, 214, 217, 224, 225, 228, 232, 237, 264, 305, 407
Harrison, 27
Harting, 137, 138
Hartung, 203
Herschel, 1, 16, 20, 21, 32, 169, 314, 460
Hickman, 197, 208
Hickman & Spencer, 327, 330
Higson, 165, 213
Homolka, 298
Houdaille, 265, 305

Hunt, 33, 169

Ives, 538, 540, 543

Jacobsohn, 181
Johnson, 28, 30, 149
Jones, Chapman, 211, 407
Jones, L. A., 213, 214, 215, 375

Kennett, 29, 149
Kepler, 4
Kollmorgen, 121
Konig, 171, 173, 298

Lambert, 412
Lanier, 323
Lea, Carey, 202, 203
Le Clerc, 360, 524
Lee, 113, 122, 144, 166
Lehrmann, 85, 321
Libri, 3
Liesegang, 31
Lippmann, 538
Lockett, 304, 411
Lumiere & Seyewetz, 201, 202, 284, 290, 297, 298, 318, 319, 320, 321, 326, 331, 339, 350, 433, 438, 545
Luppo-Cramer, 164, 176, 196, 200, 203, 298, 300, 351
Luther, 227

Maddox, 28, 149
Manly, 35
Mansfield, 29
Marion, 34
Martin, 143
Maxwell, Clerk, 540
Mayer, 504, 506, 514
Mayer & Walter, 299
McDonough, 545
Mees, 165, 187, 375
Mees and Sheppard, 151, 211, 225, 239, 257, 258, 262, 264, 265, 267, 274, 315, 326
Merte, 131
Mills, 174
Monckhoven, 355

Namias, 281, 348, 442, 445, 446, 449, 492, 511
Nietz, 260, 274, 277
Nietz & Huse, 345, 360
Neuhaus, 201
Nicol, 459
Niepce, 8, 11, 537
Norris, 25

Owen, 488
Owens, 202

Partington, 509
Petzval, 110, 142
Piper, 36, 316, 318, 357
Poitevin, 33, 35
Ponton, 33
Pope, 175, 182
Porta, 3
Pouncy, 34
Prett, 516
Purdon, 310

Rawlings, 36
Renwick, 164, 201, 203, 205, 217
Rohr, 77
Ross, 108, 118, 121, 125, 133, 143, 146
Rudolph, 99, 117, 120, 123, 124, 128, 129, 130, 143
Russell, 195, 295
Rzymkowski, 258

Sayce & Bolton, 26
Scheele, 7, 203
Schuler, 351
Schulze, 5
Schwarz, 203
Schwarzschild, 213
Scott-Archer, 21
Sedlaczek, 358, 447
Shaw, 439
Sheppard, 152, 159, 160, 164, 197, 201, 207, 352
Sheppard & Wightman, 165
Simpson, 31
Slade, 165
Snodgrass, 372
Sutton, 26, 108
Steinheil, 109, 116, 125
Stenger, 351

Stokes, 272
Strauss, 291
Svedberg, 165, 197
Swan, 34
Symes, 512

Taupenot, 25
Taylor, 134, 136
Thomson, 458
Toy, 197, 206
Trivelli, 197, 208

Underberg, 437

Valenta, 176, 321, 355
Vallot, 569
Venn, 507
Vogel, 170, 204
Voigtlander, 110, 113, 117, 137, 138, 147

Wall, 36, 298, 405, 450, 491
Warmisham, 113, 120, 136, 139
Warwick, 315, 321
Waterhouse, 171
Watkins, 237, 259, 267, 269, 273, 302, 305
Watson, 116
Wedgwood, 7
Wellington, 356
Wightman, 196
Willis, 33
Windoes, 328
Worel, 569
Wollaston, 105

Young, 539

Zaepernick, 517
Zerbe, 488
Zschokke, 83, 85, 104

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